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TECHNICAL PAPERS

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REGIONAL
TECHNICAL CONFERENCE

*"Extrusion and Injection–
Machines and Materials"*

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MARCH 1-2, 1967

Sheraton-Boston Hotel
Boston, Mass.

SOCIETY OF PLASTICS ENGINEERS, INC. • EASTERN NEW ENGLA[ND]

"EXTRUSION & INJECTION - MACHINES & MATERIALS"

Regional Technical Conference

Sponsored by

Eastern New England Section

Society of Plastics Engineers, Inc.

March 1-2, 1967

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Regional Technical Conference of the Society of Plastics Engineers, Inc.

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WHAT YOU CAN EXPECT FROM AN EXTRUDER MANUFACTURER TODAY AND TOMORROW

473

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Sales Product Manager

Davis Standard Div.

Mystic, Conn.

To explain the machinery manufacturer's current position, it is necessary to review briefly the past fifteen years.

The primary emphasis in the plastics industry during the past fifteen years has been in polymer technology. Every major petrochemical company has spent millions of dollars developing new materials and expanding basic materials. The bulk of the engineering talent in the plastics industry has been devoted to designing, building and proving out processing equipment for the manufacturer of resins.

Production equipment to turn these resins into end products was largely developed by individual businesses with a specific problem to solve. These people worked with machinery manufacturers and made innovations designed to improve their own particular process and end product.

About two years ago the emphasis began to shift. The market for the three major resins - polyethylene, polystyrene and PVC - reached a point where basic resin manufacturing processes were established and fixed.

Of course, during this past fifteen-year period, the machinery manufacturers developed laboratories, the resin manufacturers developed laboratories and a great deal of work has been done. We must recognize, however, that the work applied to general processing techniques has been applied by the few rather than the many in our business.

It now becomes obvious, with the resin manufacturing techniques established, that a transfer of engineering talent will take place. During the next ten years we expect to see the majority of engineering emphasis applied to processing techniques for end product production. There is no question that with this mass of engineering talent applied to processing there will be rapid developments in process machinery throughout this next ten-year period.

All the available market forecasts for use of plastics, tend to show that we are in a unique stage of development. For example, one school of thought is that the price of resins will be dropping throughout the next five years, due to the increased capacity for resin production currently under construction and due to competition from imported resins. If past history is meaningful, then we can expect if resin prices go down to open up vast new marketplaces for plastics production that are currently denied to us by the price of our raw materials.

An example of this is foam styrene. The basic techniques are available to

produce foam styrene cups and plates and they are being produced for specialty market areas. If, however, the price of styrene were to drop, then the market currently held by high quality paper items would be opened to foam products and again, if past history is meaningful, this penetration would take us three to five years.

We must recognize that today when it comes to processing equipment we are operating, you as the user and we as the supplier, in many cases, in an area where defined technology simply doesn't exist. You quite often buy and we quite often build what essentially is a process development line. It involves the application of all of our available experience and all of your available experience plus some assumptions and guessed-estimates to put this line together. In this type of joint venture, there appears to be this large area of misunderstanding. Quite often the top management of your company believes that they are buying a proven process for the production of their product when, in fact, this is a process development pilot line. Now, obviously, your top management hesitates to commit a quarter of a million dollars or so without some assurance of success.

The best insurance is a 100% warranty of operation. If you are doing business with a reputable house on a pilot process line that exceeds the limits of available technology, you will not get a 100% warranty on operation.

Your job as process engineers for your company and our job for our company is to evaluate these projects properly and to supply your management with a very clear understanding of the risks involved. How do we get around this today? One way is that we make this pilot line, and I'll use the word loosely, "flexible". If you can't sell the risk factor in a pilot line to your management for a given process then quite often you say, "Okay, let us design the line to run a product and utilize current available technology". You then say, "Let us incorporate in this line features that will allow us to use it as a pilot on a developmental line".

This is fine, assuming you recognize the fact that you must pay for this flexibility both in dollars and cents for the equipment and in perhaps a lower success factor in your development work.

It is often better to face your management and define the risk involved in a complete pilot process line rather than minimize the risk by trying to build a dual purpose unit. Things are improving along these lines and with many companies it is now possible to present a pilot line of process equipment and say that the risk factor is 20% out of 100% that the line will not produce at the rates and quality levels required, because of limits of available technology. However, we still have many top management people in this business who simply refuse to accept the fact that we are today pushing the levels of proven technology and, therefore, risk must be assumed in order to prove out processes.

Let us look at what any competent machinery manufacturer can do for you today. Each major supplier to this industry has, of necessity, obtained its major growth in special areas within our industry. This is why you have a particular manufacturer with a reputation for excellence in certain types of processing equipment. For example, our friends at National Rubber Machinery Company are well known far and wide as a major source for rubber extruding machines.

Today, when you decide to buy an extrusion line the price you pay for this line will be established by three prime factors. The first is the quality level of the actual hardware you are acquiring. Facing the facts, if you compare "apples for apples" on basic hardware, the suppliers will break down pricewise into three groups - a high quality group consisting of 3 to 4 major suppliers, an intermediate group, and a low-cost group. Believe me, you will get exactly what you pay for,

no more and no less.

The second factor is the experience level of the given process area that the manufacturer has. In some process lines it is now possible to turn your problem over to an extrusion equipment manufacturer and he will supply a complete line for manufacturing a product from beginning to end. In this case, you will be paying for this technology as part of your purchase price.

The third factor, and probably the one hardest to measure in its value to you, is the "personality" of the company you are buying this equipment from. By this I mean the ability of the machinery manufacturer to be ofservice to you after the sale. Will you get prompt action on service? Can you expect continued help in improving your process technology? Will the company honor not only its legal obligation to you in terms of warranty but its moral obligation to support and further the aims of its clients?

This, as I said, is the hardest thing to measure and yet, in an industry that moves as fast as ours, where many process developments are really started as a combination of your best guess and our best guess as to what will work, the "personality" of the company with whom you are doing business becomes extremely important.

Today, then, you can expect to buy the level of quality you are willing to pay for, plus, in some areas, a high degree of technology along with this equipment. What about tomorrow? We feel sure that all the major extrusion equipment suppliers will be staffing and planning to provide a much greater degree of process engineering ability than we have in the past. We will be assuming complete systems responsibility to a greater degree than ever before. We will concentrate efforts in research areas to gain firmer knowledge of single screw extruder operation and we probably will be engineering, developing and testing complete process lines, offering them as a total system to the marketplace on a regular basis. Heretofore, most of these complete process lines are not in a nature of a plant arrangement between the machinery manufacturer and a given client.

Therefore, tomorrow will bring a higher degree of process engineering available to you from the extrusion equipment manufacturer.

I would like to mention one factor that is a key element in the relationship between YOU as purchasers of equipment and US as suppliers. That factor is "quality" of the end product you want to make.

For example, in the PVC pipe you can hear rates on any given size of pipe that vary by at least 25% in lbs./hour on the same extruder and the same schedule of pipe. The difference in these rate figures from plant to plant is in the quality of the pipe being produced. If you ask a machinery manufacturer, "How many pounds an hour of this product can I get" and you get an answer like "600 pounds an hour should be no problem at all" - LOOK OUT!

The rate of your extrusion process line on an hourly basis will be governed nine times out of ten by the quality level you must have in your own products in order to sell it to your marketplace. If you can define the level of quality you must have, we can tell you within a reasonable range the output rate you will get on a given process line. It won't be as high a number as you like to see. One thing you can count on is that quality levels in all types of plastics end products will be higher in the next ten years and, conversely, processing lines and processing techniques currently in use will be limited in output by this quality requirement.

We expect new techniques and new equipment to be introduced on a rapid basis over the next ten years that will provide quality in rate levels to allow penetration of many of the market places currently denied to the plastics industry.

9578-01

EXTRUDER SCREW DESIGN DEVELOPMENTS - FASTEST MOVING AREA OF DEVELOPMENT

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The most dynamic area of technological advancement in the extrusion field today is in extruder screw design. Extruder screw technology has advanced steadily over the years from the low performance diminishing pitch, constant depth, short L/D screw, to the high performance, long L/D metering screws of today. Stimulii for these changes in screw design have been requirements for higher output rates, increasing emphasis on product quality and the development of new polymers with improved chemical and physical properties, which require improved processing techniques.

In order to study the many extrusion processing variables and their effect upon both extruder performance and polymer properties, laboratories of both polymer manufacturers, extrusion machinery manufacturers, and in some cases, end users, have been equipped with a wide spectrum of electronic devices to sense and record pressures and temperatures of the polymer at various points in the barrel of the extruding machine (Figure 1).

The most sophisticated arrangement employed to date is the Western Electric digital recording system.[1] With this type of system, voltage outputs from the pressure and temperature instrumentation are converted into digit pulses and then recorded on paper tape. In this manner, high speed records are obtained which can be readily processed on electronic computors. The plots made by the computor of temperature and the amount of variation existing and pressure vs. screw position eliminate a tremendous amount of handwork normally required to produce these curves.

Through the use of these electronic devices it now has become possible to evaluate the wide variety of extrusion screws now in use, and the extrusion parameters which affect their operation. It is also possible to develop mathematical models of these extrusion screws and accurately predict their performance with a specific polymer under various operating conditions.[1]

Results of laboratory testing and field development under production operating conditions indicate that maximum performance from conventional screws has been attained and their level of performance requires considerable upgrading to meet future requirements in both economical operation and quality.

During the past several years a number of new screws have appeared on the market. The design of these screws deviates from the conventional screw in several ways. However, the basic principle behind these designs has been to obtain a more homogenous melt at a lower stock temperature with less variations in temperature and pressure at higher output rates.

Flow streamlines in the screw channel must be changed in some manner to mix the various temperature melt present in a conventional screw channel. This streamlining of flow if not changed or interrupted, leads to an extrudate of poor homogeneity which is difficult to process at economical rates and also results in products of poor quality. Following is a brief description of several screws which have been developed in an attempt to overcome this problem.

The National Rubber Machinery Co. "QLT"[2] screw was developed to obtain a "quality low temperature" extrudate by use of a reverse flight decompression stage. The reverse flight changes normal channel circulation or flow. This change of channel streamline flow in the reverse flight stage mixes the non-uniform temperature and viscosity melt delivered from the first stage of the screw into a high quality extrudate, which is then pumped from the second stage metering section into the die system.

The Maillefer S.A. BM[3] screw was developed to deliver to the extruder die system a homogenous melt, without need of screw cooling. The screw is designed with a diminishing width feed channel while the metering channel increases in width towards the delivery end of the screw. A clearance gap is located between the extruder barrel and the screw flight. This gap is only on the flight that forms the leading edge of the feed channel and allows the plasticized stock to flow from the feed channel back into the metering channel. Since the gap between the flight and the screw is of constant depth, all material moving through this gap is subjected to the same shear, thus producing a uniform high quality extrudate. Since the screw does not require cooling a high mechanical efficiency is obtained as most of the energy produced by the drive motor is converted into shear heat and absorbed by the material.

Barnett, Klein, Mallory and Marshall[4] of the Western Electric Co. have designed a screw incorporating the "compression relief" concept. This screw operates on the principle that a higher flow rate than drag flow exists in the terminal compression channel and the relief section acts as pressure dropping device to keep the melt pumping section pressure constant. Barrel temperatures in the transition area of this screw have a greater effect on the output variation as the differential between screw temperature and barrel temperature affect drag flow. The greatest advantage reported using this type screw is the ability to operate at higher screw speeds with a deeper metering section than a conventional metering screw without increasing stock temperature fluctuations.

The Davis-Standard "mixing screw" utilizes mixing rings located within the metering channel to disturb the flow streamline normally present in conventional metering type screw channels. This disturbance of channel flow or circulation is accomplished by periodically breaking up the streamlines by use of mixing rings located at fixed intervals in the metering section of the screw. Since all melt must pass through the slots in the ring, the channel streamline flow is disturbed. The disturbed flow then later reforms in a random manner further down the screw. The use of a deep metering section in conjunction with the mixing rings minimizes heat buildup due to shear and helps keep the stock temperature down. The greatest disadvantage of the deep meter is its pressure sensitivity as the extrudate output rate falls off more rapidly as head pressure is increased.

None of the aforementioned screws is the final answer to all extrusion problems, but each in its own way achieves improvement in one or more extrusion problems.

In our work to design a screw to handle the wide range of polymers now in use in the extrusion field and the still broader range of polymers that are becoming

available for extrusion, the "mixing screw" principle still offers the greatest promise. To date, excellent performance has been attained with the "mixing screw" on the following materials. High density polyethylene, polystyrene, polypropylene, nylon, vinyl chloride, polycarbonate, polyester and others. No one standard design "mixing screw" can handle all the aforementioned polymers and produce optimum performance. Each "mixing screw" must be specifically designed for range of applications it is to be used for.

Since most problems can be shown to originate during the melting process, future work will be and is now being directed towards study of this area of screw, the so-called feed and transition sections. The objective of these studies is to improve the heat transfer process and smooth out the transition of the polymer from a solid to a melt.

What are the variables in screw design that can affect this area of the screw? Reports on experiments made by Klein, Marshall & Friehe[5] on a $2\frac{1}{2}$" 24:1 instrumented extruder indicate the following:

In most experiments it was observed that the surface temperature of the screw is most always the highest temperature component in the extrusion system. Under neutral screw conditions the slope of the curve of the screw surface temperature vs. screw position is fairly steep in the feed and transition section. The curve then levels out and remains equal to the stock temperature of the material being extruded, or slightly above it. The degree or level of temperature that the screw attains is dependent upon many variables. Long shallow metering screws extruding high viscosity crystalline type resins have a high screw root temperature in the metering section. This high screw root temperature in the meter has an effect upon pressure level of the polymer and can cause maxima in the transition area of the screw and minima in the metering section of the screw. This variation in pressure profile would indicate variation in the screw dimensions as the source; however, it can now be shown differences in relationship between screw temperature and barrel temperature have a pronounced effect upon channel drag flow and this can be the direct cause of these pressure profile variations.

Polymers of low crystallinity which soften in direct relationship to temperature rise are extremely sensitive to screw root temperatures and barrel temperatures in the transition area of the screw. As the pellets move from the feed channel of the screw into the transition area, the pellets in contact with the barrel wall and the screw root begin to soften and move to the pushing edge of screw flight. The melted material collects in this area, of the flight, and induces the development of pressure in the channel. The volume of melt and magnitude of pressure are dependent upon the rate of fusion through conduction of heat from the barrel and frictional heat developed by shear.

If the length of the transition section of the screw is short, materials that are hard and low in percent crystallinity create a high degree of frictional heat by interaction of motion with other pellets and also by rubbing contact with the surface of the screw and barrel wall. Since the rate of heat transfer is greater through the barrel wall and screw than the material itself, these surfaces rapidly change in temperature. This temperature change in total temperature level or a differential temperature between the screw root and barrel wall affect channel drag flow the resultant being a cause of pressure profile variations in this area of the screw (surging).

Several experimental tests have been made in the laboratory to confirm this analysis. Previous work done on both the laboratory $2\frac{1}{2}$" 24:1 extruder and $4\frac{1}{2}$" 24:1

extruder has indicated that the transition and feed area of a larger machine are more critical to changes in number of diameters of length, barrel temperatures and screw temperatures than the smaller machine. Two screws were evaluated with different length transitions. All other screw dimensions were kept the same with the exception of the feed length which was shortened 5 diameters to increase the transition from 5 diameters to 10 diameters. Tests were then run with high-impact polystyrene pellets under identical barrel heats, head restriction and extruder screw speed. The results as plotted in Figure 2 established that the long transition screw had a higher output (17%), lower pressure maxima in the transition, reduced pressure minima in the meter and better uniformity in pressure and temperature variations of the extruded resin. Subsequent tests using the same head restriction, but different screw speeds have correlated with this data.

When an extruder screw is cooled, uniformity of temperature and pressure of the extrudate is generally better than neutral screw operation. However, this uniformity is usually attained at a sacrifice in output rates.

Maddock[6] expressed the reduction in output rate due to screw cooling as a result of effect of a frozen or slow moving layer of material reducing effective channel depth, thus increasing the effective rate of shear and mixing intensity.

Laboratory tests recently performed with .95 .7 MI linear polyethylene extruded with temperature controlled screws indicate that this is only partially true. Analysis of the data indicated that the greatest factor in the reduction of rate on cooled screws is the large pressure drop in the transition area of the screw. Several tests made in the lab indicated that the reduction in pressure profile of a neutral screw vs. a cooled screw was 90% in the transition area and 20 to 30% in the metering section. To further confirm these test results a screw was plugged and cooled up to the beginning of the meter. The output rate still dropped to the rate of a fully cooled screw. The original colored polymer was then flushed with neutral resin for a few minutes. The extruder barrel was then cooled and the screw jacked out. No layer of color material was found fused to the screw in the metering section. Tests performed with other polymers indicate the same general results. Materials of lower percent crystallinity (vinyl and polypropylene) show slightly less reduction in output rate for the partially cooled screw vs. the completely cooled screw.

To further study the effect of temperature control on an extruder screw several tests were run in the lab under the following conditions: Virgin high density polyethylene, .950 density .7 MI pellets were mixed with a red 24:1 letdown masterbatch and the mixture was then extruded on a $2\frac{1}{2}$" 24:1 extruder using a temperature controlled, water cooled, conventional metering screw. After equilibrium was attained on all components of the system, the extruder feed was changed to natural resin. At this time, the extruder was abruptly stopped, the barrel rapidly cooled, and the screw removed with a hydraulic jack. The ribbon of material which remained on the screw was then removed, cooled and segmented at each turn of the flight in order to examine the respective channel flow (Figure 3).

At all points where there was a full melt within the channel a thin layer of the original colored material remained at root surface of the screw. The depth of the colored layer was greater at the pushing edge of the flight in the feed section as there was only a partial melt in this area. This greater amount of residual colored material which collected at this point due to channel circulation remained in this area and was gradually carried down the screw and mixed with the natural resin. This process continues as shown in Figure 4 slowly reducing the percentage of colored material left in the screw channel. If the extruder was allowed to operate over a longer period of time with neutral resin as a feed stock all the

remaining colored material would eventually flush out. The effect this slow moving layer of material has upon channel drag flow is fully not understood, and further experimentation will be required before an extruder screw can be designed to perform with the uniformity obtained by screw cooling, and without the inherent loss in output rate.

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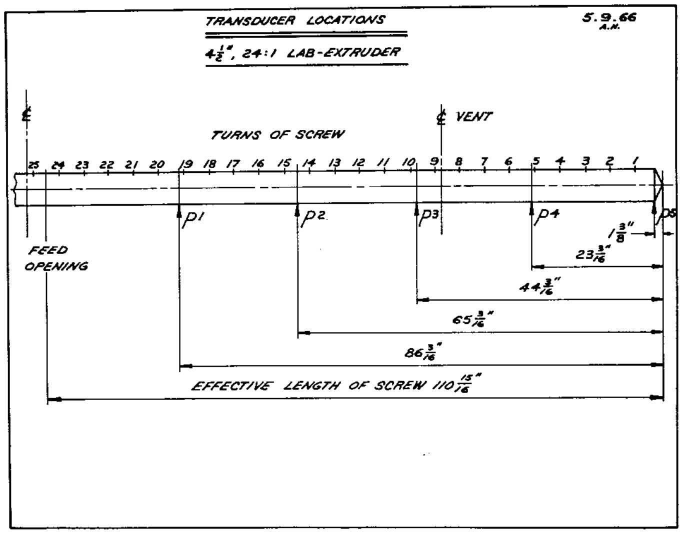

FIGURE 1

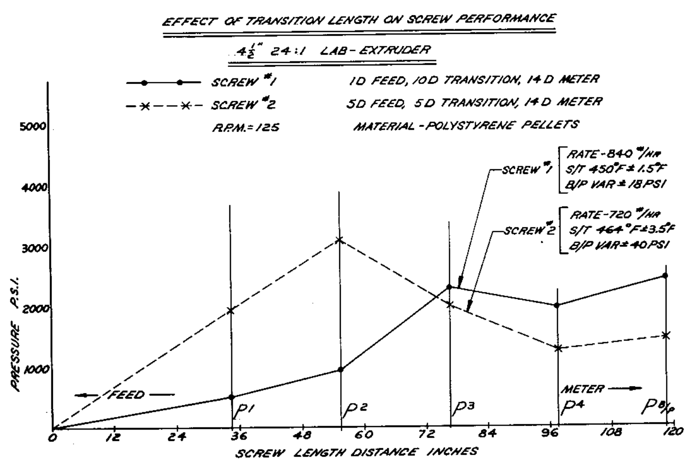

FIGURE 2

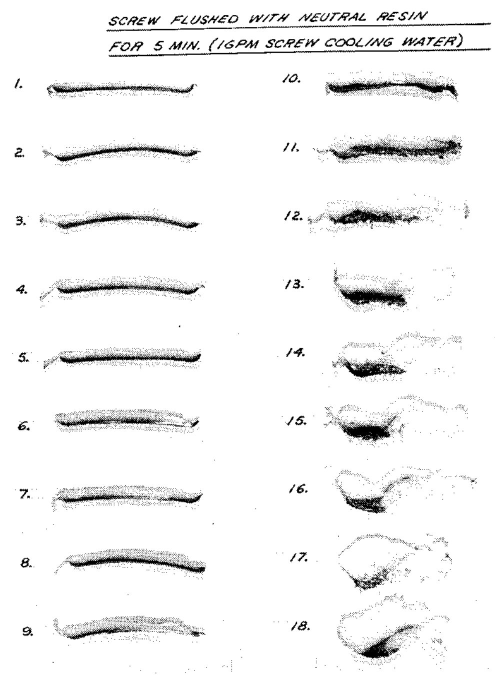

FIGURE 3

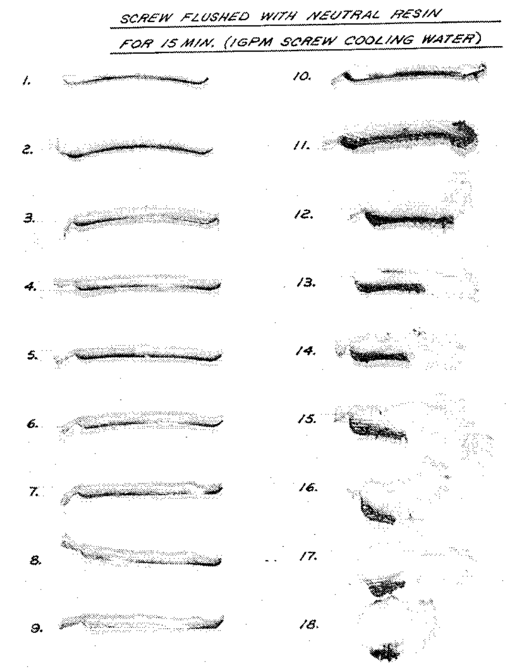

FIGURE 4

9578-02

APPLICATION OF COORINDATED DRIVE SYSTEMS FOR PLASTICS EXTRUSION LINES

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Robert H. Soderberg

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New Haven, Conn.

INTRODUCTION

The choice of an electrical adjustable multi-motor drive system and the sophistication and accuracy of its regulator depends to a major degree upon the following factors:

1. Type of product to be manufactured - product tolerance accuracy required.
2. Type and characteristics of plastics machinery to be used.
3. Environmental atmosphere of machinery and drive location.

Major technical advancements in electrical drives and regulators in the past twenty years have produced dependable and highly accurate electrical line shaft systems for multi-motor drives applications, virtually eliminating the mechanical line shaft single drive motor system so commonly used in previous years.

ADJUSTABLE SPEED DRIVES - THE STATE OF THE ART

The development of solid state components such as transistors and controlled silicon rectifiers in the past few years has permitted the development and marketing of electrical drive systems that were only a dream in the minds of electrical designers ten years ago. Permit me to present a brief comparative review of the presently available choices of adjustable speed drives. In all cases we are examining these drives as to their relative cost, and adaptability for plastics machinery multi-motor drive installations. The output characteristics are in each case compared on a constant torque basis as this type of power output is one most commonly required on today's plastics machinery.

A. Mechanical Adjustable Speed Drives (Belt Type)

Advantages

1. Low initial cost
2. Technical simplicity
3. Wide variety of mechanical and servo type electrical modification permitting operation in almost any plant environment
4. Relatively high efficiency
5. High speed accuracy with synchronous A.C. drive motors
6. Inherent regenerative braking

Disadvantages

1. Limited maximum H.P. size
2. Cannot start and accelerate under controlled conditions from zero speed.
3. Speed can only be changed during running condition
4. Belt and sheave wear restrict minute speed or speed setting adjustments
5. Restricted operational speed range

If we view the above drive from a multi-motor application standpoint, we can eliminate some of the above disadvantages if we connect these units to an adjustable frequency source and utilize them as a means of draw or ratio control at each point in the drive system. If each mechanical drive is then supplied with a synchronous motor, we can obtain precise speed accuracy between units as well as essentially zero speed starting and accelerating. The type of drive used on the main adjustable frequency power supply whether rotating alternator or static A.C., then becomes a study of overall drive system accuracy and cost.

B. Magnetic Drives Air Cooled/Water Cooled

Advantages

1. Generally lowest cost electrical drive system
2. Wide operating speed range if water cooled units are used above 25 H.P.
3. Inherent "clutch" action as well as adjustable speed drive
4. Inherent constant cooling regardless of output speed, permitting use for continuous "stall" torque operation
5. Tachometer feedback regulator (standard)
6. Relatively low power regulator required
7. Regenerative speed braking available
8. High adaptability for multi-motor drive system
9. Stationary field - absence of brushes or commutator
10. Relatively no maximum H.P. limitations

Disadvantages

1. External duct cooling air system required for air cooled units in extreme dust or chemical corrosive atmosphere
2. Water cooled units require good supply of clean uncontaminated water, not readily available in some areas of the country
3. Efficiency low below 50% speed

C. D.C. Drives (Static)

Advantages

1. Rapid cost reduction in recent years due to static control.
2. Wide speed range (with integral A.C. motor mounted blower)
3. Inherent current limit
4. Regenerative braking (General Industry Availability 1967)
5. Availability of large H.P. sizes
6. No water cooling required
7. No reduced voltage starters required for large H.P. installations

8. Good efficiency under wide speed range conditions
9. Precise accuracy availability
10. Wide range of electrical modifications
11. High adaptability for multi-motor drive system applications

Disadvantages

1. Commutator and brushes require external duct air cooling for extreme dust or chemical atmospheres
2. Total power regulator required
3. Transformer required for operation on 550V power lines and on 220V lines 100 H.P. and larger
4. No power line isolation as standard

D. A.C. Adjustable Frequency (Rotating Alternator)

Advantages

1. Electrical simplicity in multi-motor drive system
2. Inherent accuracy between slave motors on multi-motor installations
3. Low cost on relatively small connected H.P. sizes

Disadvantages

1. Not practical for high connected H.P. installation where wide speed range required, due to significant large alternator losses requiring oversize main alternator drive and resulting excessive cost.

E. A.C. Adjustable Frequency (Static)

Advantages

1. Inherent extreme speed accuracy to .01% of set speed
2. Wide speed range
3. No rotating environmental limitations
4. Mechanical A.C. motor simplicity and availability of wide variety of mechanical modifications

Disadvantages

1. High initial cost
2. Technically complex A.C. static controller

THE SOLID STATE REGULATOR

The selection of the degree of accuracy of the regulator must be chosen as a requirement of the accuracy of the product to be manufactured and the nature of the machine or driven load. The tachometer feedback regulator has become a general industry standard on multi-motor drive installation.

A. Tachometer Feedback Regulator Accuracy

1. Load regulation - stated as a plus or minus deviation from set speed with a zero to 100% load change. Specified as a percentage

change based on max. speed or set speed.

2. Drift regulation - stated as plus or minus deviation from set speed under essentially steady load conditions, specified as a percentage change based on max. speed or set speed for 24 hour operational time.

With reference to the plastics machinery process lines in use today, the subject of drift regulation becomes the most significant factor in system accuracy.

B. Choice of System Coordination

1. Tachometer Follower
2. Common Reference

Both of the above schemes have been commonly used for regulator coordination; however, it has been found that as the complexity of the multi-motor drive system process line increased, the common reference power supply with individual ratio adjustments, without individual drive load fluctuations affecting any other drive in the system (Figure 1). This system permitted the addition of drives to an existing process line without complex electrical packaging changes as long as the reference of the regulator was compatible with the existing master reference power supply.

By designing all regulators with a compatible reference supply, it then becomes possible and highly practicable to use a variety of drive types in any one system process line utilizing the optimum characteristics for each drive point location (Figure 2).

C. Digital Regulators

This available new system can properly be termed the ultimate regulator by producing essentially zero percent load regulation and zero percent drift. The normal motor mounted tachometer generator used on tachometer feedback systems, which produces a linear output of voltage or current proportional to speed is eliminated and substituted with a device of similar appearance called a digital rotopulser. This device produces an exact predetermined quantity of pulses per drive shaft revolution unaffected by external conditions such as variations in ambient temperature, etc. The comparative reference power supply now becomes a precise adjustable oscillator with a rate pulse output matching the rate output of the feedback rotopulser. A digital/analog conversion circuit is furnished for both feedback and reference supply so that the final comparative signals are analog and are fed to the final output regulator power stage. We are no longer measuring a deviation of voltage or current based on an error of one or more drive rpm, but rather we are measuring a deviation or error signal based on a minute fraction of one rpm.

The use of this device in the plastics process systems will increase as the automation of this industry expands in its technical content. The inherent accuracy of this regulator will demand ultra precise machining and concentricity of the rotating machinery it will power if maximum product results are to be achieved.

THE EXTRUDER

This particular machine is the one common factor to all types of plastics process lines. Regardless of type of drive used, the end result is to achieve an accurate stable output or volume of material. The effect of speed accuracy of the drive on this end result is not the complete factor without taking into consideration the effect of applied temperature control and pressure and screw design.

The electrical industry drive engineer considers the extruder as a steady load of high friction content. The choice of the regulator and its accuracy should be considered from a standpoint of steady state drift accuracy to produce a desired steady machine output without excessive speed change for long periods of time.

Condition 1

If the speed of the extruder screw and thus the speed of the extruder drive is linear with the output of the extruder in terms of material pounds per hour, we can then consider that the extruder can be coordinated with the remaining machines in the process lines if its output produces a linear change in tolerance dimensions of the product to be manufactured.

Condition 2

If these conditions in terms of the product are not satisfied then we must consider the extruder as a separate drive to be regulated under steady stable conditions at any set speed with the remaining process machines contributing most of the product tolerance specifications.

EXTRUSION PROCESS LINE SYSTEM

A. Wire and Cable Installation

The above caption can be broken into a quantity of categories commencing with the standard basic plastics extruder/capstan line with many variations (Figures 3, 4 and 5) to the continuous vulcanizing cable lines containing one or more extruders and a series of drives for each machine in the system capable of operating independently as well as coordinated with individual ratio or draw control (Figures 6 and 7). The previous explained Condition 1 exists where the extruder output is linear with speed to produce a direct change of tolerance in the product. In each type of system the entire line is accelerated from zero and product tolerance must be maintained on through to maximum operating speed. In order to accomplish this the drives in the system must be "tracked" to produce this product tolerance in both an accelerate and decelerate condition. This product uniformity cannot be achieved unless the extruder output and its other parameters produce a linear output proportional to a change in speed. In each extrusion line, regardless of complexity, there is only one machine which sets line speed of the wire or cable. The regulator for the drive at this point is most important due to the fact that its ability to maintain an accurate steady state speed will have a direct effect on the tolerance of the product being manufactured. Diameter control devices are commonly used to supplement the regulator and

produce a vernier speed correction to maintain product tolerance. The cable or wire at the position at the extruder head must be maintained in an exact geometrical position and isolated from the effects of any other drives in the system if concentricity and uniform wall thickness are to be achieved. It is for this reason that payoffs-helper capstan-takeups, etc., are either dancer or catenary controlled. The capstan drive or that drive which regulates the cable speed must be able to produce regenerative braking not only to assist in isolating the effects of the other drives in the system but also to produce a controlled deceleration without any "free wheeling" effects. The basic friction load of the extruder screw and compound supplies the braking effort on the extruder drive, thus it is not necessary to provide the regenerative braking in the extruder drive and control. When the entire extrusion line is decelerated it is therefore dictated that to maintain control under this condition that all drives in the system with the exception of the extruder be supplied with regenerative type braking.

B. Plastics Film Line

This category can be broken up into blown film type systems and sheet lines. In either case we have Condition 2 existing where the output of the extruder screw does not have a direct linear effect on the tolerance specifications of the product. The machines downstream of the extruder such as casting and pull rolls have the major direct result on tolerance of the product. It is for this basic reason that the drive system used on this process is composed of two electrical systems. The first controls and regulates the extruder and the second will regulate and coordinate all the other drives in the system with possible exception of the winder; each roll stand containing a ratio adjustment to adjust the draw or stretch of the sheet or film between each stand. It is in this area that a variation of the common reference system is best employed commonly called "cascade control" (Figure 8). This item simply means that a ratio change will be automatically made on each subsequent downstream roll without affecting the upstream roll stand speed. The total change to the line would be made on the line master speed adjustment maintaining all ratios at the same preset value. The ability of drives to maintain precise preset speed has a direct effect upon the product tolerance; thus, many fill lines commonly utilize regulators with plus or minus of 1/10 or 1% accuracy or better (Figure 9). Since the draw or stretch speed must be accurately maintained between each roll stand, it thus becomes most important that each drive be supplied with the ability to produce "regenerative braking". Without the braking effect it is impossible to maintain these conditions unless the desired draw is less than the upstream inherent mechanical friction such as gears or chains. The winder used must also coordinate with the upstream roll drives either by dancer of some type or by means of a tension transducer roll maintaining the desired tension during changes in roll buildup and line speed. Turret type winders are in common use to permit roll changes without affecting line speed. To avoid collapsing of the roll normally something other than constant tension is used commonly called tapered tension to produce a tight core and decreasing tension as the roll builds in diameter. The drive selected for this machine section again must be chosen to suit this condition as well as provide rapid acceleration on roll change.

C. Synthetic Fiber Process Lines

The characteristics of the extruder and its effect on the product tolerance is similar to the film and sheet line as Condition 2. Its drive system is separate from the downstream metering pumps and godet drive units. The regulator for the extruder is further refined to accept a pressure signal input from a pressure transducer located at some point in the extruder manifold chamber section. The purpose is to maintain a desired pressure at this point to provide constant back pressure and supply for the metering pumps controlling the flow of synthetic fiber. The signal from the pressure transducer is passed through an amplifier and hence to the drive regulator to produce and increase the drive or extruder speed on a decrease of pressure signal or conversely. By virtue of a range percentage adjustment the effect of pressure on extruder rpm can be adjusted from zero to full control of drive speed. Since the tolerance or denier of the fiber is directly proportional to accuracy of speed of the metering pumps-godets and stretch zone stands, the industry has found it necessary to utilize the most accurate drive system available utilizing synchronous A.C. motors for minimum maintenance and down time. The A.C. solid state frequency system has become virtually a standard in this industry.

CONCLUSION

The rapid technical advances in electrical and plastics machine development and automatic gauging equipment indicate a trend to the final "computorized" plastics process line. The digital drive regulator of precise accuracy, which is available today, can receive direct command signals from a central control process computor. The operation and speed of each machine can be exactly measured and observed by digital counters. The micro circuit technology developed by requirements of National Space Administration are now available to the electrical industry so that complete regulators of extreme accuracy can be constructed of minute size and yet provide greater dependability. The greatest need now in the plastics industry is the technically trained plant personnel to maintain this sophisticated equipment to provide the highest level of production and profit benefits.

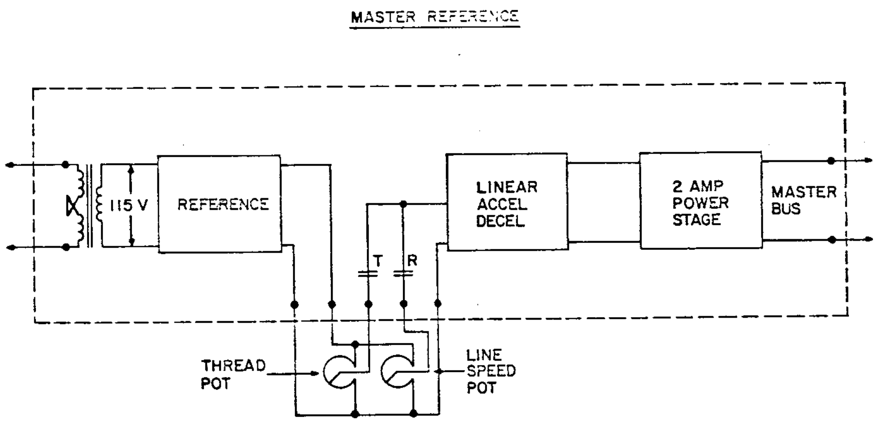

FIGURE 1

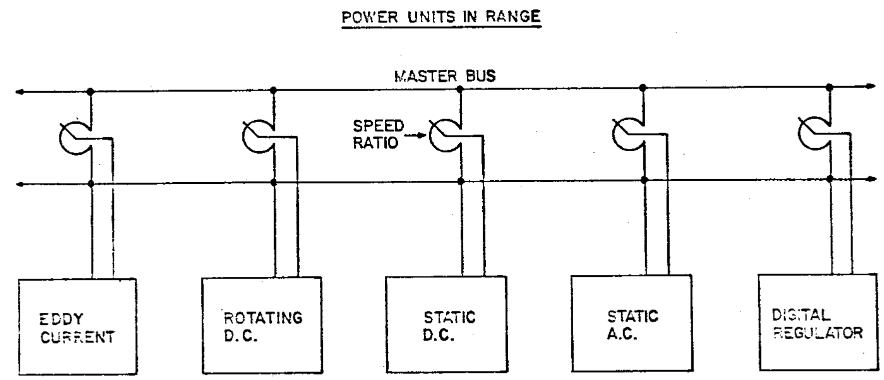

FIGURE 2

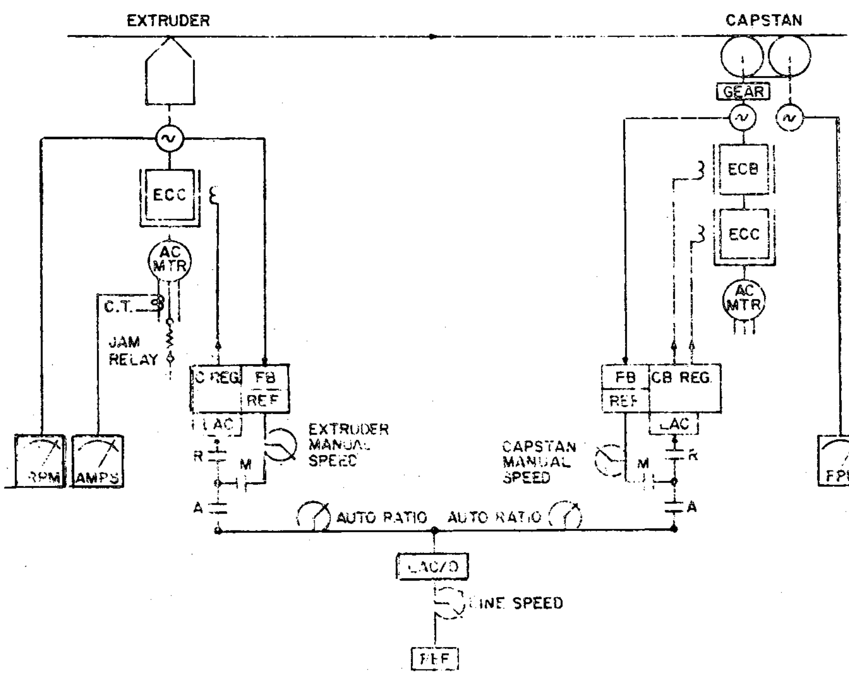

FIGURE 3

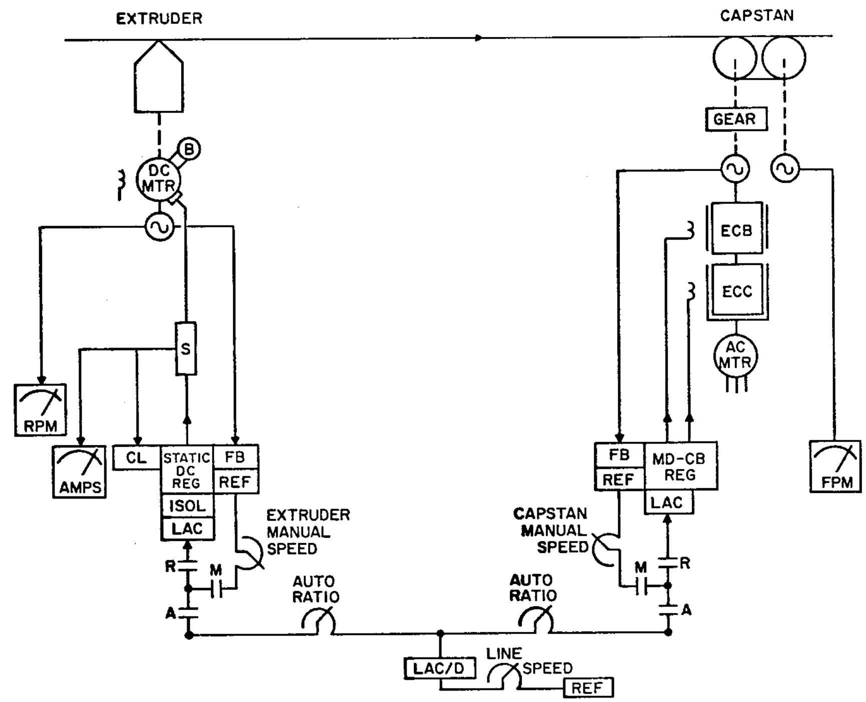

FIGURE 4

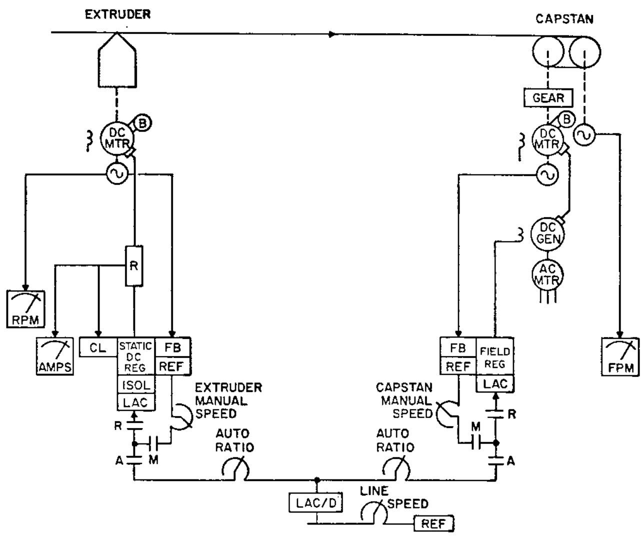

FIGURE 5

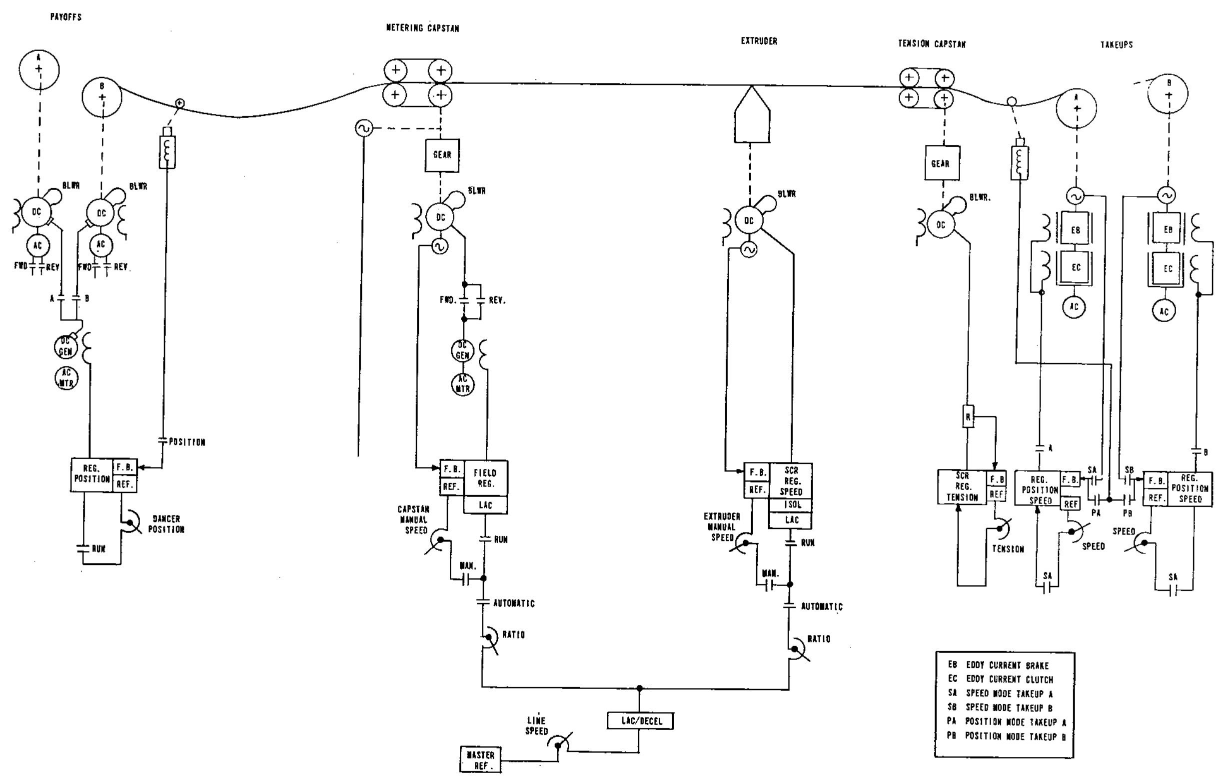

FIGURE 6

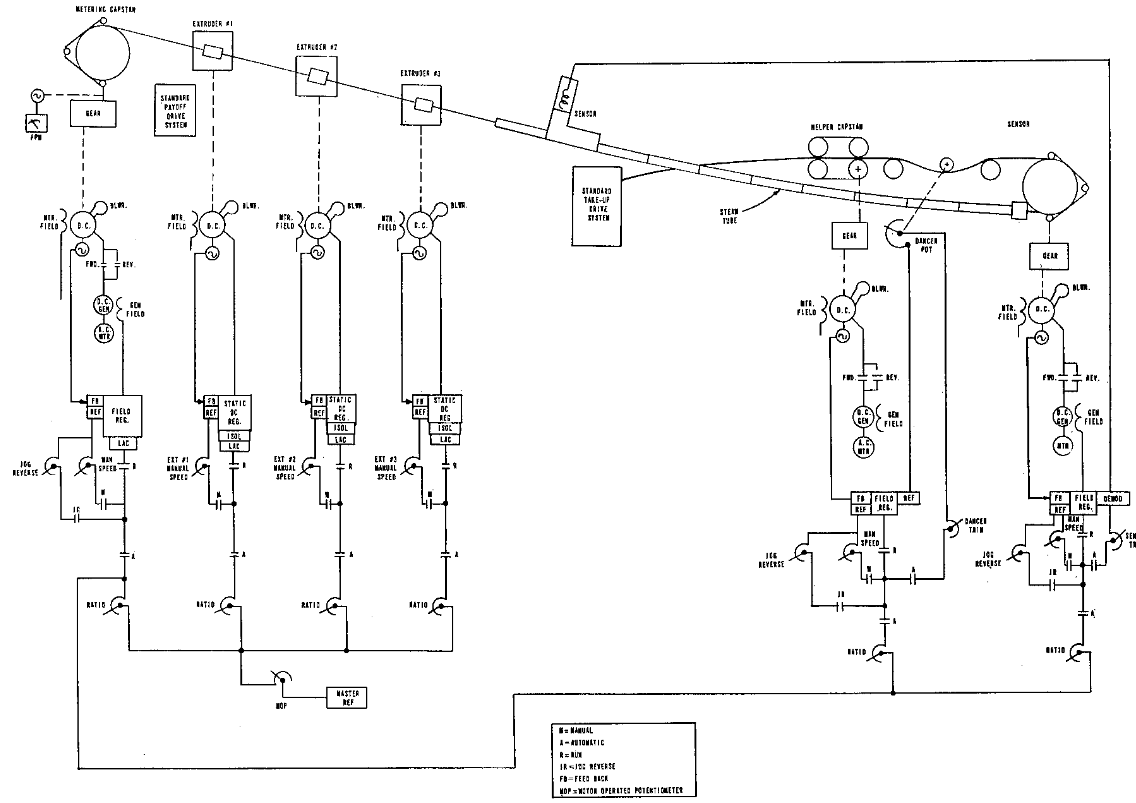

FIGURE 7

PROGRESSIVE DRAW

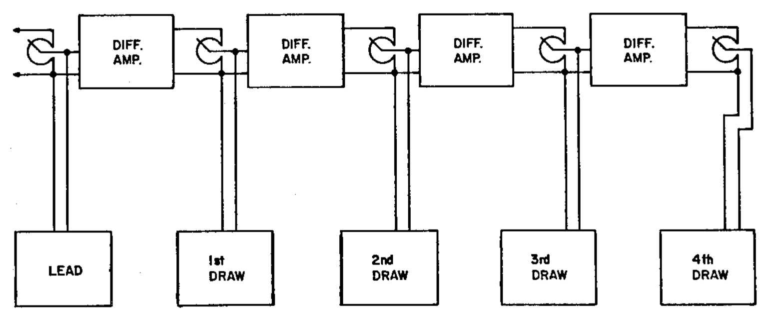

FIGURE 8

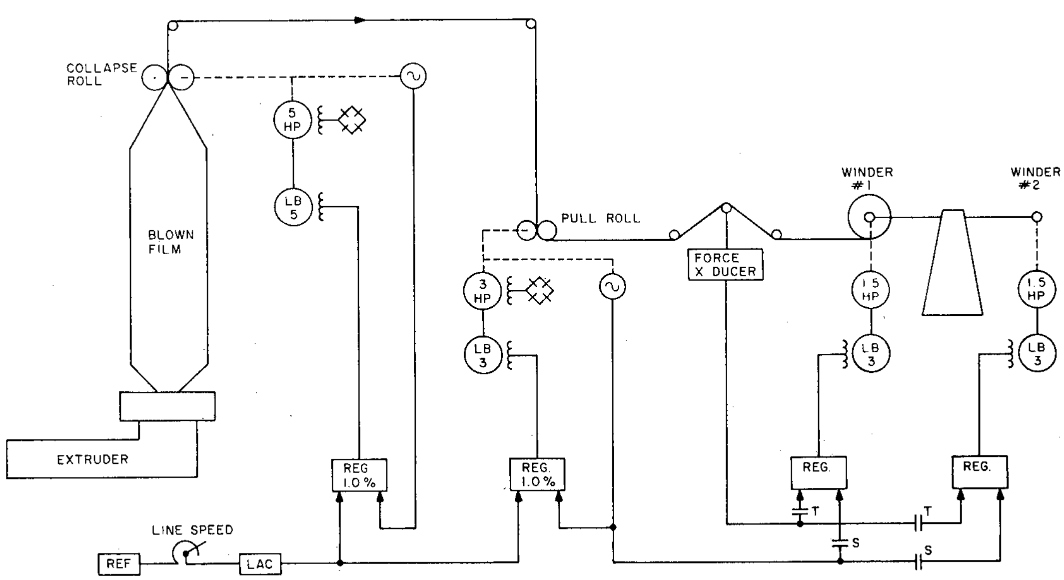

FIGURE 9

95-78-03

SCR DRIVES FOR THE PLASTICS INDUSTRY

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The latest advancement in adjustable speed drive technology is the SCR drive. It employs silicon controlled rectifiers to convert a-c supply voltage to the proper d-c voltage for the d-c motor armature. This paper deals with the characteristics of d-c adjustable voltage drives in general, and SCR drives in particular, as they relate to the plastics industry, and further to extruder drives to provide top performance and value at a justifiable cost to the user.

It might be appropriate to first review some of the more common adjustable speed drives and their application to the plastics industry. Adjustable speed drives in the plastics industry are used on extruders, mixers, calenders and film lines.

Each of these machines may require a drive capable of producing both constant horsepower and constant torque; however, the majority of their applications require only constant torque. To match the drive to the functional requirements of the machine, we must first determine the speed torque characteristics of the load and compare these with the speed torque capability of the drive (Tables I and II).

Why do we use adjustable speed drives for these applications? Undoubtedly, the primary reason is that we must have a range of controlled speed over which the drive can operate and provide a continuously adjustable speed compatible with the material being processed.

A key to applying an adjustable speed drive to a machine is knowing the controlled speed range over which the drive can operate and the continuous speed range over which the motor can deliver full rated torque. The controlled speed range is defined as the range over which the drive will provide specified regulating accuracies.

The continuous speed range of a drive may be defined as "the speed range over which the drive motor and conversion unit can deliver full rated torque". A primary consideration for continuous speed operation is the thermal capability of the motor when operating at rated torque and slow speeds.

Note that the continuous speed range of air cooled eddy current couplings (Table III) are indicated to be 17 to 1; however, they may vary depending upon the termal capabilities of the coupling. D-c drives are also thermally limited. However, extended continuous speed ranges are obtainable by proper sizing and selection of modifications to the eddy current coupling or d-c motor.

The controlled speed range can be further expanded by defining the accuracy of the regulating systems required of the drive. Speed regulation is affected by two conditions - changes in load and changes in all other variables (Table IV). Since an extruder operates at essentially a constant load, improved speed regulation to compensate for load changes is not as important as correcting for all other variables.

Compensating for speed changes due to all other variables will result in a more uniform and better product. An inexpensive motor tachometer modification will improve the regulation due to "all other variables" and, at the same time, improve the speed regulation caused by load variations.

Obviously, all of the above comments are general, and, while they do apply to SCR drives, they do not confine themselves to any particular type of adjustable speed drive. Since this paper is to deal with Silicon Controlled Rectifier Drives and their advantages to the plastics industry, we might ask: "What is the SCR drive and how does it differ from the historic M-G Set?"

An SCR drive is a regulated, stepless adjustable speed drive that uses a semiconductor device commonly known as a silicon controlled rectifier. It is an ideal type of drive for any industry because of its compact size and efficient operation.

A basic SCR drive block diagram is shown in Figure 1.

1. Reference power supply.
2. Acceleration circuit (linear time, current limit or combination of both).
3. Control amplifier.
4. SCR firing circuit.
5. SCR conversion unit.
6. D-c motor.
7. Magnetic devices (relays, contactors).

The desired motor speed is set by the speed adjusting potentiometer. A voltage proportional to motor speed, either armature voltage feedback or tachometer generator feedback, is compared with the speed reference. If the motor is running slower than the speed called for by the reference, a comparison of these two voltages (reference and feedback) will result in an error signal. The error will be amplified and cause the firing circuit to fire the SCR earlier in the cycle, so that a larger conduction time is obtained, resulting in a higher d-c voltage. If the motor is running faster than the speed called for by the reference, the error signal will cause the firing circuit to delay firing of the SCRs. This reduces the conduction time and results in lowering the d-c voltage until the motor speed has decreased to that called for by the reference.

A comparison of the size of a typical SCR conversion unit and its equivalent motor generator set is shown in Figures 2A and 2B. In terms of valuable production floor space, the SCR drive is approximately 1/3 the size of a comparable m-g set drive. In addition, the weight relationship is approximately 1/2.

The compact size of the SCR is not the only consideration to be made when comparing SCR and m-g set drives.

Relative overloads, for example, should be compared. The motor generator set is capable of sizable overloads, up to at least 200% of rated load for several minutes without danger to the system. An SCR cell operates at current densities approaching 2000 amps per square inch and does not have this overload capability. Industry standards specify SCR drives as good for 150% at rated load for one

minute. Although this standard fulfills most extruder overload requirements, additional capacity may be obtained by oversizing the SCR cell. The d-c motor will not have to be oversized as long as torque peaks are within the commutating capabilities of the motor.

After sizing the SCR cell, the next consideration should be the speed range required. There are many SCR drives on the market with published speed ranges of 8 to 1, 20 to 1, or even 30 to 1, as standard. One fact should be understood about these published speed ranges.

They do not mean that the drive will supply rated torque over the entire speed range unless some type of external cooling is supplied to the d-c motor. A good rule of thumb for applying d-c motors at reduced speed is that a motor can produce rated torque continuously to one-half of base speed. If it is to operate on a continuous basis below one-half base speed, torque must be reduced, or external cooling has to be provided to the motor in order for it not to overheat.

If continuous operation at low speeds is required, one of the following should be considered:

1. Add a motor mounted blower and filter.
2. Oversize the motor.
3. Supply separate external ventilation to the motor.

What does the listed speed range mean then? It is the range over which the drive is guaranteed to produce rated torque (not continuously) and over which all performance specifications are guaranteed to be met.

Another factor that must be considered in the design of an SCR drive is the amount of ripple voltage that appears on the d-c output voltage. Since this d-c output voltage is a rectified voltage, there is an appreciable amount of ripple voltage.

Early designs of SCR power supplies used a modified bridge type of circuit to obtain adjustable voltage output. This is illustrated in Figure 3.

A-c voltage is fed to a 3-phase full wave bridge rectifier circuit using 3 SCRs and 3 diodes. The point in each cycle at which the SCR fires determines the average d-c voltage supplied to the motor armature. The smoothing reactor in the armature circuit is provided to reduce the amount of ripple voltage across the d-c motor. It is this ripple that causes the d-c motor to overheat and, in turn, reduces the continuous speed range of the drive. Motor temperature rises are approximately 15% greater than for those operating from m-g sets.

More recent designs of SCR drives employ the six leg bridge, rather than the modified. It uses 6 controlled rectifiers, rather than 3 SCRs and 3 diodes. The basic circuit is shown in Figure 4. This design provides better form factor and does not require smoothing reactors. There are many advantages to the 6 leg designs over the modified bridge. Motors run cooler due to the reduced amount of ripple. They have essentially the same temperature rise as motors operating from m-g sets. The power unit is smaller and lighter because of the absence of reactors. Spare parts are reduced by the elimination of the diode from the conversion unit.

The efficiency of the SCR cell is very high, and because of this the efficiency of the SCR drive is also high (Figure 5). Comparison of the efficiency and power factor curves with that of a motor generator type of drive shows that

the SCR is considerably more efficient and will result in lower operating costs.

Regulating performance of the SCR drive is mainly a function of the type of regulator being used. The inherent response of the conversion unit enables an SCR drive system to be very fast. Although on extruder drives fast response is not critical when related to speed changes, it is advantageous in correcting for changes resulting from a-c line voltage disturbances. The effect of these disturbances on the d-c voltage, and thus motor speed, could be more pronounced with SCR drives than with a motor generator set if rapid response where not inherent with the SCR.

A-c line disturbances are caused by the connection and disconnection of a significant load on the power system. For example, a motor starting or stopping, or even the extruder calling for more heat in the head or barrel.

To further offset variations in speed, it is desirable to specify that the drive be furnished with an improved regulating system and, as pointed out earlier, reduce the effect of the all other variables to 2%, or even 1%.

High reliability is a prerequisite for industrial acceptance of any product. In critical process industries, such as plastics, paper and steel, the success of SCR drives is substantiated by the explosive trend toward complete adjustable speed SCR drive systems. It is forecast that by 1970, SCR drives will be utilized in nearly 80% of all new installations.

In summary, the advantages of an SCR type drive can probably best be judged by comparing it with a motor generator set. Comparative advantages of the SCR drive are:

1. Low maintenance.
2. Wide controlled speed range.
3. Quiet operation.
4. High efficiency.
5. Inherent fast response.
6. Compact size - less weight.
7. High reliability.

The most candid statement one could make concerning SCR drives and the plastics industry is that they are no longer the "drive of the future", they have arrived.

TABLE I

TYPICAL CHARACTERISTICS OF MACHINES

1. Most extruders and mixers - constant torque.
2. Center wind reels - constant horsepower.
3. Centrifugal fans and pumps - varying torque.
4. Calenders and some extruders and mixers - combination of constant torque and constant horsepower.

TABLE II

COMPARISON OF MACHINE CHARACTERISTICS AND DRIVES

Type of Load	Applicable Drive
1. Constant torque	a) Wound rotor motor b) Adjustable frequency c) Eddy current couplings d) D-c adjustable voltage (M-G Set or SCR)
2. Constant horsepower	a) Eddy current couplings (derated) b) D-c adjustable voltage motor with field control
3. Variable torque	a) Wound rotor motor b) Adjustable frequency c) Eddy current couplings d) D-c adjustable voltage
4. Combination of constant Horsepower and constant torque	a) Eddy current couplings (derated) b) D-c adjustable voltage with motor field control

TABLE III

COMPARISON OF TYPICAL SPEED RANGES FOR THE THREE TYPES OF DRIVES

Type of Drive	Continuous Speed Range	Controlled Speed Range
1. Air cooled eddy current coupling	17 to 1	17 to 1
2. Water cooled eddy current coupling	17 to 1	17 to 1
3. Adjustable voltage d-c	2 to 1	20 to 1

TABLE IV

COMPATIBLE ACCURACIES OF REGULATING SYSTEMS (CONTROLLED SPEED RANGE)

Percent Regulation Due to Load Change	Percent Regulation Due to All Other Variables*	Tachometer Required
5	15	No
2	2	Yes
1	1	Yes
.5	.5	Yes
.25	.25	Yes
.10	.15	Yes

*All other variables are defined as:

1) A-c line voltage change (10% change).

2) A-c line frequency change (2% change).

3) Ambient temperature change (15 deg. C change).

4) Drift (8 hour drift after 15 minute warmup).

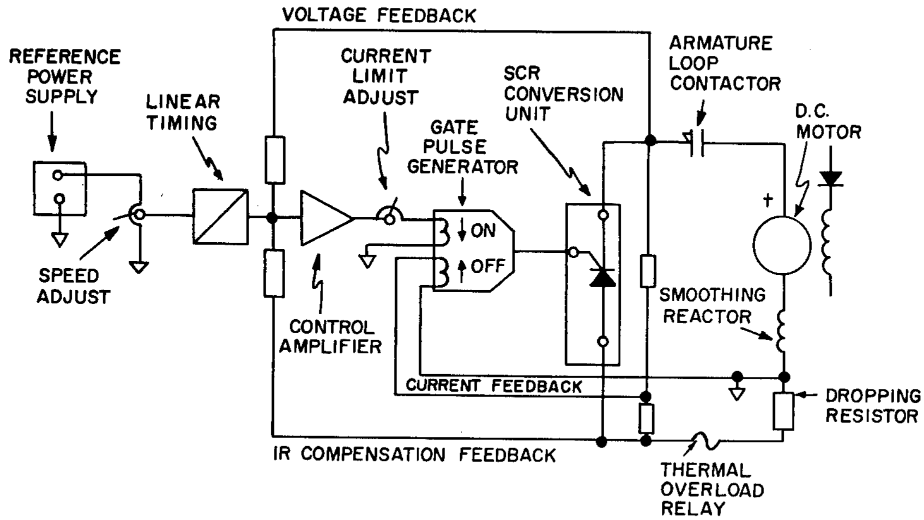

FIGURE 1: Function Block Diagram of SCR Drive

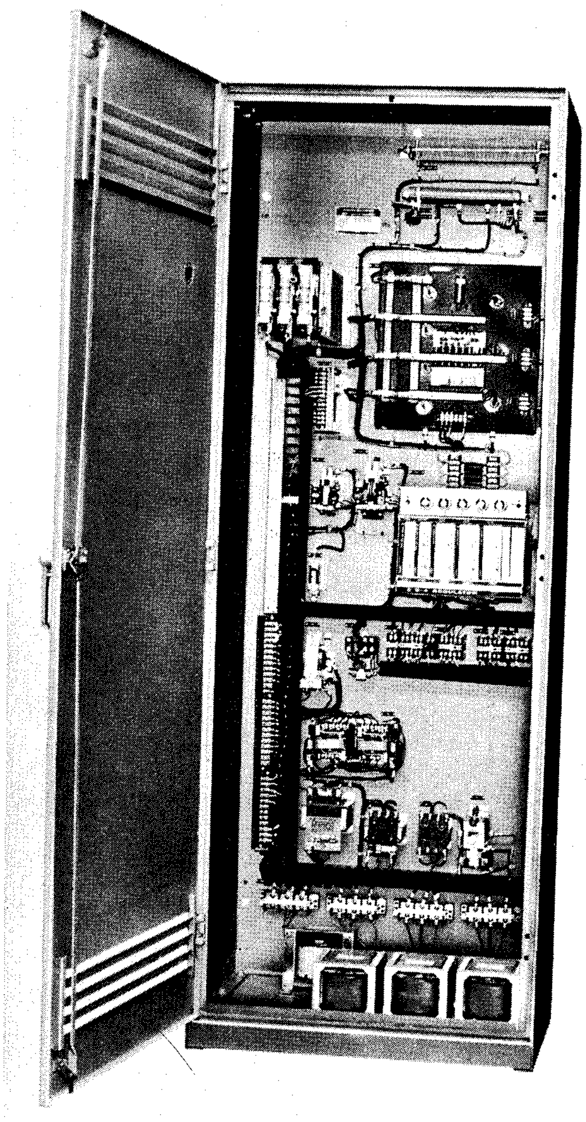

FIGURE 2A: SCR Conversion Unit

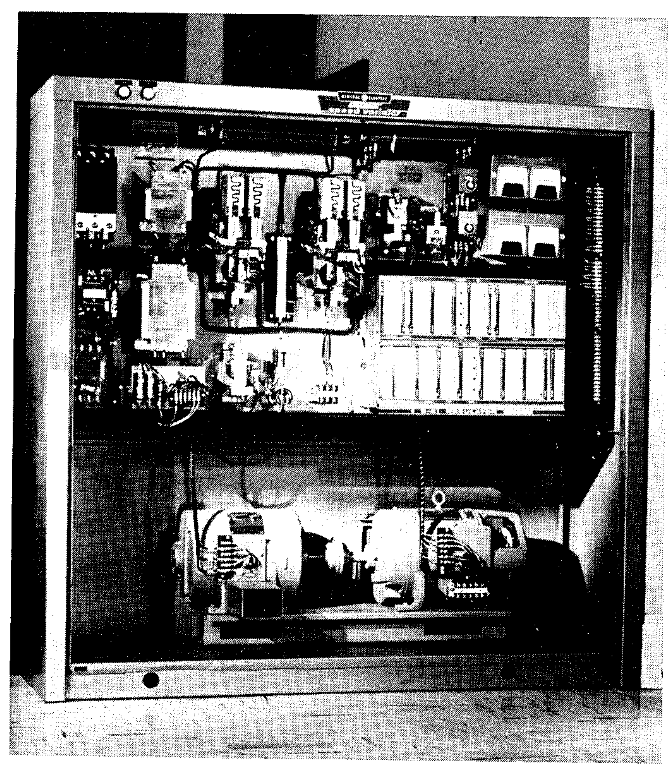

FIGURE 2B: Motor Generator Set

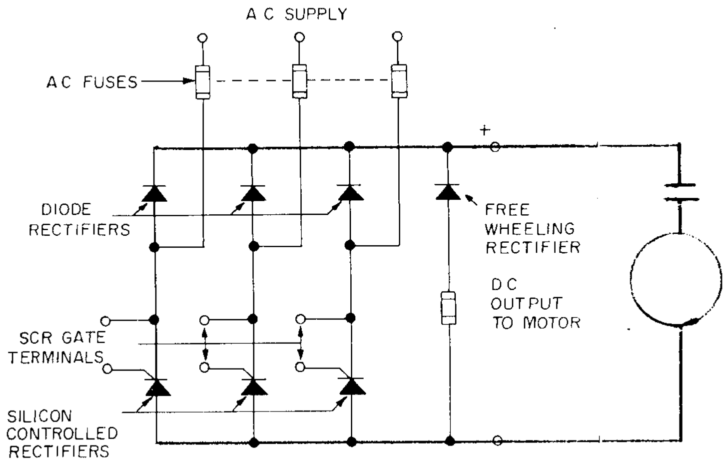

FIGURE 3

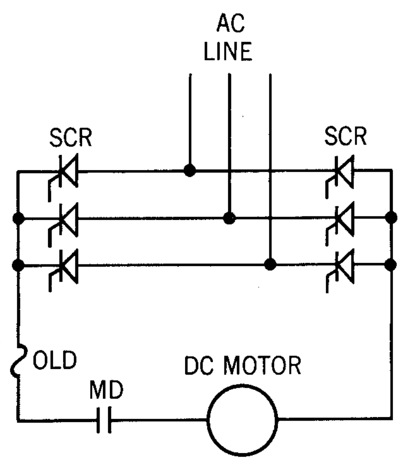

FIGURE 4

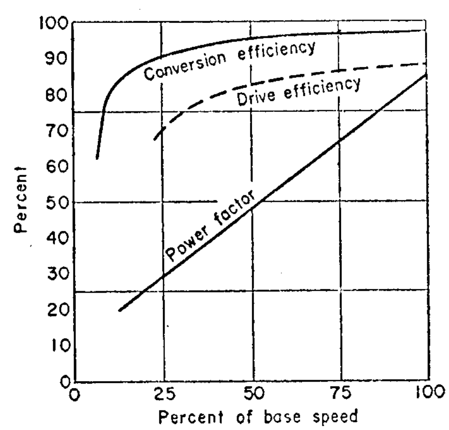

FIGURE 5

ABSTRACT

PANEL DISCUSSION: HOW MUCH FLEXIBILITY FOR FUTURE USE CAN YOU AFFORD TO BUILD INTO YOUR TAKE-OFF SYSTEM?

Moderator: Richard Senn, NRM Corp.

Panelists: A. Jonsrud, Frank W. Egan Co.
A. Harrington, Davis-Standard
C. Goulding, Goulding Manufacturing

Due to the wide variety of plastics extrusion applications by industry today, it has been necessary in the efforts of economy for the extruder and extrusion accessory manufacturer to design equipment flexible enough to cover a range of plastics. For example: In wire covering - fine wire, heavy wire, cable and CV units; in film and sheeting - sheeting lines, film casting units, and blown tubing units; in tubing and pipe - various size dies and haul-off equipment to handle a relatively broad range of products from surgical tubing, garden hose to large size irrigation pipe.

Most of these units are designed to handle the more common materials in the product category, and it is believed that in the past five years ranges of materials and sizes of equipment have been somewhat standardized due to the growing demand. The result being that equipment manufacturers can build some equipment for stock in quantity and avoid large amounts of engineering time in re-design, as long as the customer requirements are within the scope of the equipment.

On the other hand, most equipment manufacturers today are faced with requests by customers to provide special equipment to handle more exotic materials, or to have a considerably greater range capacity than would normally be provided by their standard lines. Usually the result of this is that the cost must reflect a considerable engineering expenditure and additional manufacturing time, which is often of questionable value; and if presented in the proper way to the customer he may decide that he could use more standard equipment due to the fact that his special requirements are small volume and really not a factor in his overall sales.

The panel members will attempt to elaborate on such problems during the session in order to convey to the user the limitations imposed by available equipment and the resultant costs of deviating from standards.

9578-04

POLYSULFONE

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INTRODUCTION

Although polysulfone is one of the newer thermoplastics on the market, it is rapidly getting to the place where it can no longer be classified as "new" material. It was first molded in a field trial almost three years ago. It was first offered to the general public almost two years ago.

Originally, when polysulfone was still a laboratory curiosity, there was some question as to whether a material with such a high softening point could be successfully injection molded in standard equipment. This question was favorably resolved some time ago. The combined knowledge generated by continued laboratory work and by the experience of many people who have molded polysulfone either in field trials or regular production has resulted in a set of basic rules for forming it by injection molding. I would like to review these rules briefly and then discuss a few of them in greater detail.

BASIC MOLDING INSTRUCTIONS

A. Stock Temperature

The injection molding of polysulfone P-1700 is similar to the molding of other thermoplastics with the exception that the stock temperature must be relatively high. This temperature will be between 625°F and 750°F depending on the complexity of the mold and the type of molding machine used.

B. Machines

Polysulfone can be molded in most modern machines of either ram or screw design but a screw machine is preferred. When molding polysulfone in a ram machine, the shot size should be between 30 to 60% of the machines rated capacity.

C. Molds

Molds used for polysulfone should be designed for a plastics of relatively high melt viscosity. Molds designed for polycarbonate will usually give excellent results with polysulfone, but molds designed for nylon or polypropylene will quite often have undersized

runners and gates. Runners in molds used for polysulfone should be generous in cross section and either trapezoidal or full round. Gates should be located and sized so that jetting into the cavity will be minimized. The molds should be channeled for accurate temperature control.

D. Cylinder Temperature

In beginning a polysulfone run in either ram or screw machines, the cylinder temperature controllers should be set at 600 to 625°F and then gradually raised until acceptable mold fill-out is obtained. Maximum injection pressure will usually be required. Ram speed should also be set at maximum although in some cases it may be necessary to slow the ram to minimize jetting through the gates.

Polysulfone is extremely stable at high temperatures and has been successfully run in screw machines at stock temperatures above 800°F. However, it is possible for the resin to degrade at temperatures between 750 and 800°F when the residence time in the cylinder is excessively long. This could happen, for instance, when attempting to run a small shot in a large ram machine. First signs of degradation are "splash" or "splay" marks followed by black streaks at slightly higher temperature. When these signs appear, the cylinder heaters should be reduced and the machine should be purged a few times. Splash due to moisture should not be mistaken as a sign of degraded resin nor should black contamination from other materials still in the cylinder. If wet or degraded material is inadvertently injected into a mold, the mold surface should be cleaned with a suitable metal cleaner before shutting down the press or storing the mold.

E. Purging

Before raising the cylinder temperatures to the level required for molding polysulfone, other more temperature sensitive resins should be thoroughly purged from the cylinder. This can be done with polystyrene, high density polyethylene, polypropylene or reground acrylic. An extrusion grade polypropylene is especially suitable for this as it can be purged through a relatively cold cylinder as well as through a hot one and it will not become excessively soft at the higher temperatures. Reground, cast acrylic cleans a cylinder well but tends to degrade and spit from the nozzle during ejection if used at cylinder temperature above 500°F. If the cylinder contains polycarbonate, one may go directly to polysulfone without any intermediate purge. Polysulfone will mold at stock temperatures 50 to 100°F higher than polycarbonate.

Normal procedures should be followed when shutting down a machine containing polysulfone. It is not necessary to purge the resin from the cylinder but a few shots should be ejected while the cylinder cools. In a screw machine, the feed should be shut off and the screw left empty.

If a change to a different plastics is to be made, the polysulfone should be purged before dropping the cylinder temperature. Again, extrusion grade polypropylene is recommended for purging but polycarbonate, polystyrene or acrylic resin may also be used.

F. Mold Temperature

The optimum mold temperature for molding polysulfone will vary with the part thickness. Temperatures of 200-210°F are satisfactory for simple parts of at least 75 to 100 mils in thickness. Complex parts of long flow or thin cross section may require temperatures as high as 300 to 320°F. These high mold temperatures should be used to produce relatively stress free parts which will have the maximum degree of chemical resistance and thermal aging characteristics. However, very high mold temperatures should not be used unless necessary for they complicate the molding process and lengthen cycles for all but thin parts. Faster cycles will be obtained on thick parts if the mold temperature is reduced to 140 to 160°F.

G. Mold Lubrication

When a mold lubricant is required a light dusting with zinc stearate is recommended. Many of the "non-marking", "paintable" lubricants are also suitable but they should be used with caution as some of these can cause stress cracking. All lubricants will mark the parts and build up on the mold if they are used in excessive amounts.

H. Drying

Polysulfone absorbs moisture from the air during storage and, if molded in the undried condition, the moisture will cause surface streaks or "splash" on molded articles. Therefore, polysulfone must be thoroughly dry before molding. Oven drying for four hours at 250°F-275°F is recommended. Dehumidifying hopper dryers may also be used, providing they reduce the moisture content of the resin to below 0.05%.

I. Regrind

Regrind may be used in reasonable quantities providing it is dry.

COMBATTING STRESS CRACKING

These are the basic rules for molding polysulfone. I would like to discuss a few of them in greater detail, starting with the statement that mold temperatures of 300°F to 320°F will give relatively stress free parts which will have the maximum degree of chemical resistance.

There are a number of chemicals which will cause polysulfone moldings to crack if the stress level within the part is high enough. Included among these chemicals are the aromatic and chlorinated hydrocarbons as well as ketones and esters. Of course, polysulfone is not recommended for use in these environments. However, many parts require momentary resistance to certain aggressive chemicals even though, in their principal use, they may never come in contact with them. For example, parts that are painted will require at least momentary resistance to paint and lacquer solvents. Others which are periodically cleaned, might at some time come in contact with an aggressive cleaner such as tri-chlorethylene instead of the "recommended safe" cleaners.

It is awkward to instruct the user not to expose polysulfone parts to aggressive chemicals and such instructions are practically impossible to enforce. Normally, the fabricator has little control over the part once it is shipped.

Therefore, it has been necessary to use a different approach. This is to find ways to reduce the stress level in molded parts so that they will not crack even if they are inadvertently exposed to aggressive chemicals.

The normal injection molding process results in high internal stresses in the parts. The molder not only wants good looking parts but also might have tight dimensional tolerances to meet. And, above all, he wants a short cycle. He will keep stock and mold temperatures low to shorten cooling times and he will pack the part well to maintain dimensions and avoid sink marks. Parts molded under these conditions will contain high residual stresses.

There are certain molding techniques that will minimize these stresses. One of these is to avoid excessive packing. Also, one should fill the mold rapidly, but not so rapidly that jetting occurs, and stock temperature should be relatively high. However, the most reliable method of lowering stresses is to use a hot mold. Stress levels in polysulfone parts molded in a 300°F to 320°F mold will usually be so low that the parts will not stress crack, even when dipped in an aggressive solvent such as acetone.

A similar reduction in internal stress levels can be obtained by annealing the parts after molding. Oven annealing at 330°F will do this but will take one to four hours. Rapid annealing in a glycerine or mineral oil bath is preferred. Parts up to 0.10" thick can be annealed in one minute in 330°F glycerine and the glycerine can be washed off in hot water. Thicker parts require slightly longer annealing times. Parts 1/4" thick should be annealed for 5 minutes and the thermal shock of the hot glycerine should be reduced by immersing the parts in boiling water before and after annealing.

The methods just described will usually solve the stress cracking problem but both methods have certain disadvantages. Using a hot mold will lengthen overall cycles and annealing will cost time and money simply because it is an extra step in the manufacturing process.

Figure 1 shows the effects of mold temperature on cycle time. The mold used in this experiment was a family mold for making test specimens. It contained 1/8" thick tensile and flexural bars but the cycle length was controlled by the time required to cool the third part, a 1/4" flexural bar. Increasing the mold temperature from 200°F to 300°F increased the overall cycle from 50 to 75 seconds or 50%.

The penalty for using a high mold temperature is not as great when molding thinner parts. The hotter mold will help mold fillout without increasing the overall cycle to as great an extent as thicker parts, providing, of course, that the cycle length is not determined by the time to set up a heavier sprue and runner.

When one is attempting to reduce the stress level within a molded part, there must be a way of detecting and measuring the stress that is present. Polaroid film has been used for this purpose but it is limited to transparent parts and is difficult to interpret quantitatively. A different method of estimating the stress level has been devised by the Union Carbide laboratory. Tests were made to determine the minimum tensile stress required to cause crazing in compression molded specimens when they were exposed to a variety of solvents. The results are shown in Table I. A tensile stress of less than 200 psi caused crazing in ethyl acetate or acetone but a stress of at least 2400-2600 psi was required to cause crazing in carbon tetrachloride. With the information in this chart, the residual stress in a molded part may be estimated by exposing sample parts to these solvents and noting which ones cause cracking.

MELT FLOW

The reasons for the high stock temperatures, large runners and gates recommended for polysulfone, can be readily understood if one is aware of this plastics' properties in the melt form. Melt viscosity and spiral flow data have been given in previous papers on polysulfone. Of the two, the spiral flow information is usually the more readily understood. Therefore, I would like to show and discuss briefly the two spiral flow graphs shown in Figures 2 and 3.

The first one compares the flow of polysulfone at various temperatures with the flow of several other well known plastics. You will note that at stock temperatures of 400-550°F the molding grade polypropylene, impact polystyrene and the styrene acrylonitrile copolymer flow considerably farther than polysulfone flows at stock temperatures of 650-750°F. The flow of molding grade polysulfone was about the same as that of polycarbonate although the stock temperature required to obtain this flow was 70 to 100°F higher.

In Figure 3 the spiral flow of polysulfone is shown at different spiral thicknesses. A flow of only 2" was obtained at a spiral thickness of .030" but this increased to 14 inches at .080". This data gives an indication of the difficulties to be expected in filling thin walled parts and should serve as a warning to avoid long, narrow runners.

STOCK TEMPERATURE

Obtaining the high stock temperature necessary to mold polysulfone has not been an important problem. Although a few people have refused even to try to reach the required temperatures, most molders have taken this in stride, finding that operating at these temperatures is not a problem in modern molding equipment.

It is well known that stock temperatures in a screw machine will usually run significantly higher than indicated cylinder temperature. This temperature difference varies with the machine and with the conditions used. High screw speeds and high back pressure will increase the stock temperature as will screws with high compression ratios. Typical stock temperatures at different cylinder settings for a screw machine running polysulfone are shown in Table II.

Operation at these high temperatures for extended periods does not appear to have an adverse effect on molding machine cylinders. We have operated one screw machine in the laboratory on polysulfone for more than three years and others for shorter periods without any unusual signs of wear or corrosion.

It is characteristic of polysulfone, however, to build up a black layer of carbonized resin in the melt zone of a cylinder. Much of this will stick to the plastics when the machine cools and will come out as black scale and specks on start-up. A thorough purge with polysulfone at this point will usually eliminate the contamination.

GLASS FILLED POLYSULFONE

The structural properties of polysulfone are significantly improved by glass reinforcement. When compared to unreinforced P-1700, the tensile strength is increased by 70 to 80%, the tensile modulus by 300% and the creep and thermal expansion are significantly lowered. Mold shrinkage is reduced and self-extinguishing properties improved. The heat deflection point of polysulfone is affected only

slightly by glass reinforcement.

In Table III the properties of a typical 30% glass filled polysulfone are compared with those of the unreinforced resin. The tensile strength and modulus are increased. The water absorption and chemical resistance do not change much. Although the Izod impact strength increases as shown here it has been our experience that the practical toughness of polysulfone decreases with glass reinforcement.

Molding the glass filled products is not difficult. Again a screw machine is recommended. Stock temperatures required run a little higher than for the unfilled resin but cycles are usually shorter because of the rapid set-up and low shrinkage of the filled product. The appearance of parts molded from glass filled product. The appearance of parts molded from glass filled polysulfone is typical of a glass filled resin and is not as attractive as the unfilled plastics.

In choosing between polysulfone and glass reinforced polysulfone, one must weigh the high rigidty and lower creep against the higher cost. The reinforced product has a gravity of 1.4 and costs about $1.50 per pound. This brings the cost per cubic inch to about 7.5 cents compared to 4.47 cents for unmodified polysulfone.

The data shown in Table III and in Figures 4 and 5 which show the modulus vs. temperature and creep vs. time of reinforced polysulfone, were obtained in Union Carbide's laboratory. The glass filled materials, however, were not made by our company. Union Carbide does not intend to produce or market these products but they may be purchased either from Fiberfil, Inc. in Evansville, Indiana or from Liquid Nitrogen in Malvern, Pennsylvania.

A number of other modified polysulfone products have been made experimentally and are under evaluation. In due time, I expect that some of these will be available for general use.

ACKNOWLEDGMENTS

The author wishes to acknowledge the valuable contributions made to this paper by T. E. Bugel, H. F. Eckard, J. Latosky, M. E. Sauers and R. B. Staub.

TABLE I

CRITICAL STRESS LEVEL FOR POLYSULFONE IN SELECTED SOLVENTS

Solvent	Approximate Critical Stress, psi
Acetone	< 200
Ethyl acetate	< 200
1,1,1 Trichlorethane	500-600
2-Ethoxyethanol (cellosolve)	1200
Ethylene glycol monobutyl ether (butyl cellosolve)	1400
Diethylene glycol monoethyl ether (carbitol)	1800
Carbon tetrachloride	2400-2600

TABLE II

TEMPERATURE OVERRIDE IN SCREW MACHINE

Cylinder Temperature, ^{o}F	Stock Temperature, ^{o}F
625	700
675	735
700	760
725	775

TABLE III

TYPICAL PROPERTIES OF GLASS REINFORCED POLYSULFONE

Property	p-1700	30% Glass Polysulfone
Specific gravity	1.24	1.41
Tensile strength, psi	10,200	17,100
Tensile modulus, psi	360,000	1,090,000
% Elongation	50-100	2
Flexural strength, psi	15,400	25,200
Flexural modulus, psi	390,000	1,200,000
Izod impact strength, 1/8" specimen, ft.lbs./in.	1.3	1.8
Tensile impact strength, ft.lbs./in.^{3}	400-500	60-100
Water absorption, % 24 hrs. at	0.22	0.22
equilibrium, 73^{o}F	0.62	0.59
Heat distortion temperature, ^{o}F at 264 psi	345	369
Coefficient of linear expansion, in./in./^{o}F x 10^{-5}	3.1	1.6
Mold shrinkage, in./in.	.007	.003

CYCLE VS MOLD TEMPERATURE

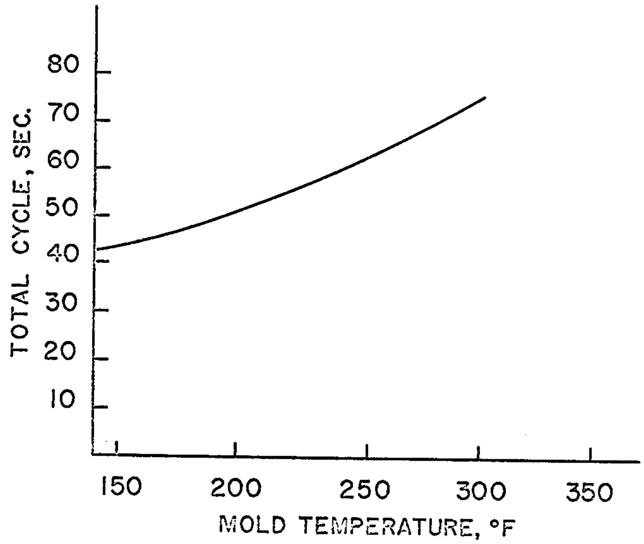
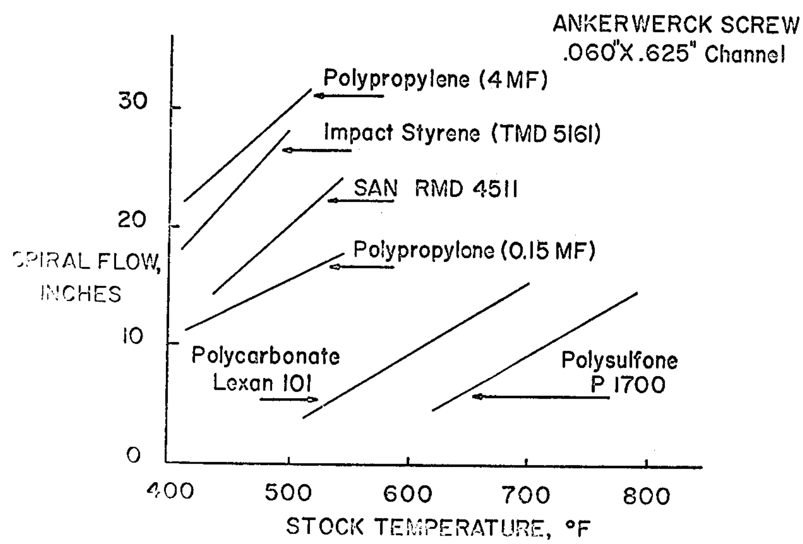


FIGURE 1

SPIRAL FLOW VS TEMPERATURE

FIGURE 2



SPIRAL FLOW VS WALL THICKNESS

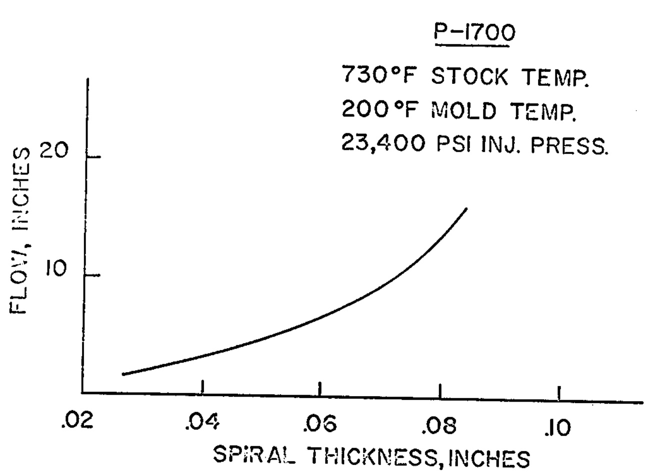


FIGURE 3

FLEXURAL MODULUS VS TEMPERATURE
POLYSULFONE

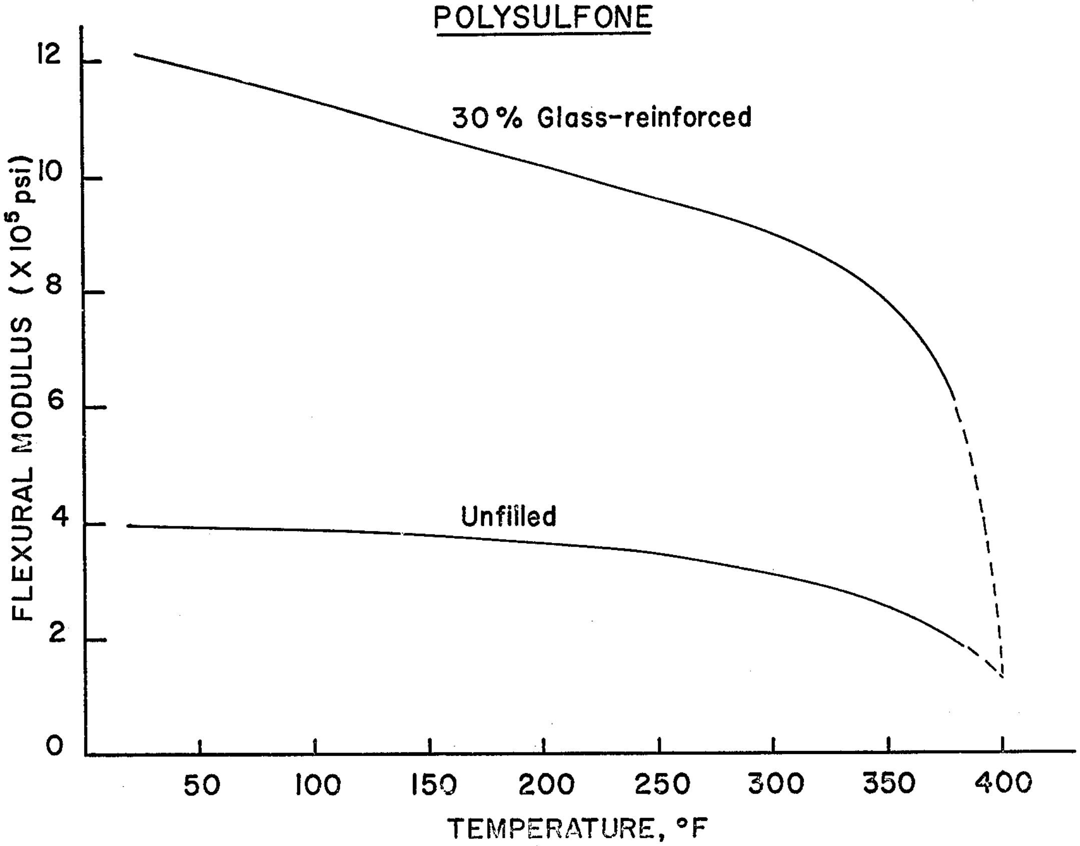


FIGURE 4

CREEP BEHAVIOR OF POLYSULFONE
3000 PSI AND 212 °F

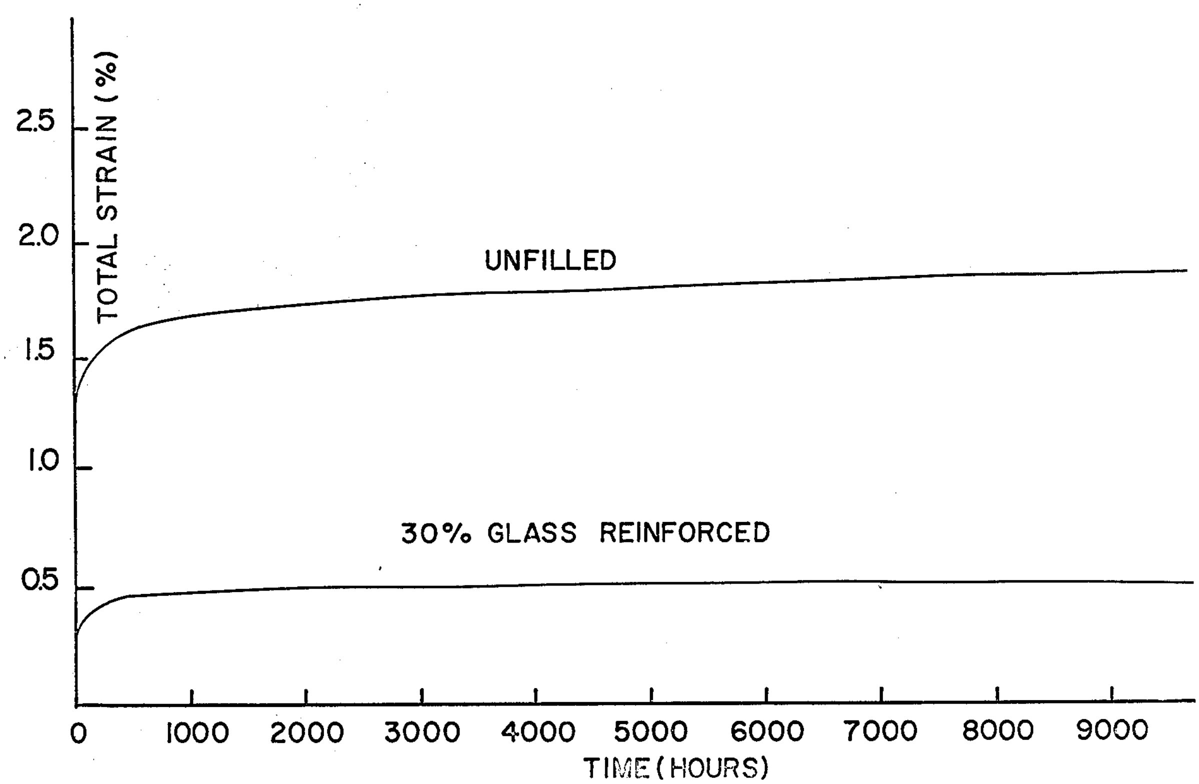


FIGURE 5

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WARPAGE ANALYSIS OF INJECTION MOLDED POLYOLEFINS 9578-05

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D. E. Proctor and G. N. Schooler

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There are three physical properties of all polyolefins which can cause problems during fabrication. They are the material's low thermal conductivity, high shrinkage and high zero shear viscosity. In injection molding any, or all, of these can make themselves evident by the production of warped parts. However, the interdependence of these same properties make it most difficult to determine which of the three is the most critical. The desire to know more about our resins caused us to look again at the method used to evaluate their warpage characteristics. To date, most of the studies have been concerned only with high density polyethylene.

In the past, our warpage studies were made on a center-gated mold having a cavity 0.070" deep and 8" in diameter. The discs were molded in incremental part weights from minimum-to-fill to flashed. The results were reported as the weight range which produced flat discs plus the range from minimum-to-fill to flashed. A disc was classified as "warped" when the deflection was as much as 1/16", but no distinction was made as to the degree of warpage. Ordinarily the final appearance of the disc would be described as "slightly cupped", "an extreme potato chipping", or something of that nature. With this information it was possible to report relative warpage as the percentage of flat parts to the total part weight range. Although this information had some meaning when comparing the warpage characteristics of a group of resins, it was never possible to ascertain just how much the discs had warped without having them laid out before you or at least talking to the technician who had conducted the evaluation. It soon became apparent that a more analytical test was needed.

Since warpage is most prevalent in large flat sections, a new mold having cavity dimensions of 10" x 14.5" and a depth of 0.070" was built for the evaluation. The projected area of 145 sq.in. was settled upon as the maximum realistic size for high, medium and low melt index resins in a .070" slab. Again for greater flexibility in evaluating different resins, the slab was center-gated. To reduce the probability of internal stresses setting up as the result of filling the cavity through a small gate, a 0.350" diameter gate was used. As with the old test, incremental part weights from minimum-to-fill to flashed were molded from each resin evaluated.

Figure 1 shows how warpage is measured using the large slab. The slab is placed inside the measuring jig and a depth micrometer is used to measure the deflection from flat. As shown in the photograph, the warpage is somewhat symmetrical so it was decided to measure the two points of maximum deflection and use the

average of the two as a warpage factor. The corresponding part weights and warpage factors can be presented graphically and then it is possible to study the warpage behavior of different resins over a large range of molding conditions. We now had a method of analysis which continued to have meaning after the test slab was destroyed. The following comments are concerned with the application of this particular test to different resins and molding conditions.

Because of the material's high zero shear viscosity, it is necessary that high pressures (20,000 psig) be used to inject the molten resin into the mold. The fluid plastics' compressability then causes internal stresses to be molded into the finished part and, if the mold temperature is too high, these same stresses often result in the part failing during use. Figure 2 shows the effect of relieving these stresses by annealing the test slabs in a 250°F oven for thirty minutes and allowing them to cool at room temperature for 24 hours. This one graph alone illustrates that the improved heat transfer properties resulting from packing the mold greatly override any warpage which might result from stresses being molded into the resin.

Figure 3 shows the effect of injection pressure on warpage. At 9,000 psig the pressure is just not adequate to fill quickly and pack it out against mold cavity. Consequently, warpage is at a maximum. As the injection pressure is increased, the rate of filling the mold also increases and warpage is kept at a minimum.

Each resin has an optimum processing temperature which results in the best part on a particular mold. This certainly is true in articles with large flat sections which might cause problems by warping. As shown in Figure 4, when the temperature is too low (375°F), the resin is so viscous that the increase in internal stress causes a slight increase in warpage. Increasing the temperature to 450°F without a corresponding increase in the overall cycle means that less heat is removed from the slab and warpage results due to differential shrinkage after removal from the mold.

As was mentioned before, the flattest part is produced when the mold is filled as fast as possible. This fact could not be more dramatically illustrated than as shown in Figure 5. The higher effective injection pressure of a reciprocating screw machine fills the mold faster than does the plunger machine. This not only results in a flatter part but also a lighter one. The development of the reciprocating screw machine has certainly solved many molders' problems by allowing them to process resins which were not possible to mold before. In addition to the higher effective injection pressure, the melt temperature is more homogeneous which alleviates the problem of warpage caused by differential shrinkage.

Just as the machinery manufacturers are improving their products, the resin suppliers can now offer materials which are not only easier to process but also result in the production of a better part. Figure 6 illustrates the importance of resin selection when molding large flat sections. The two materials having the least amount of warpage are from the group of narrow molecular weight distribution resins now on the market. In addition to being flatter, thin sections molded in the narrow molecular weight distribution resins ordinarily have more impact strength.

The ultimate machine and material for molding large flat sections has yet to be produced but definite improvements are being made in both.

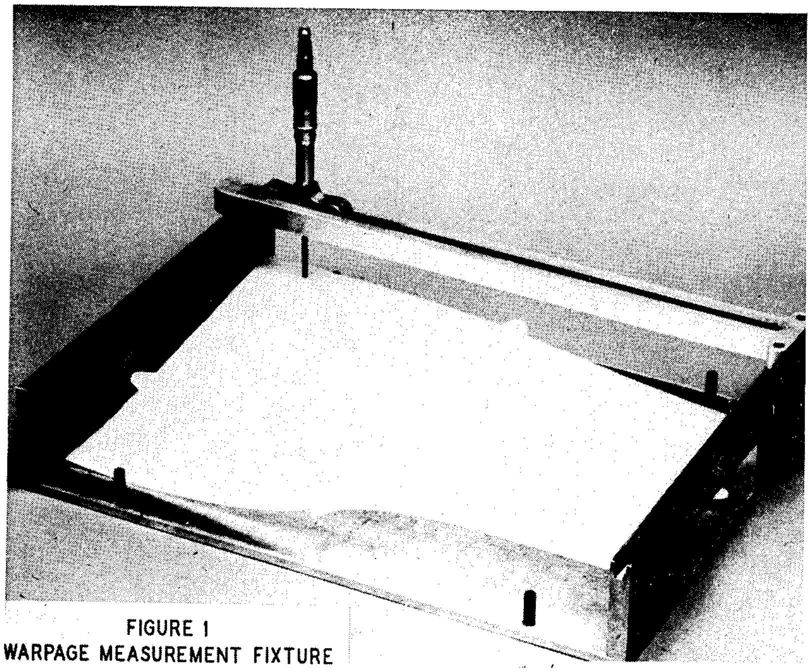

FIGURE 1
WARPAGE MEASUREMENT FIXTURE

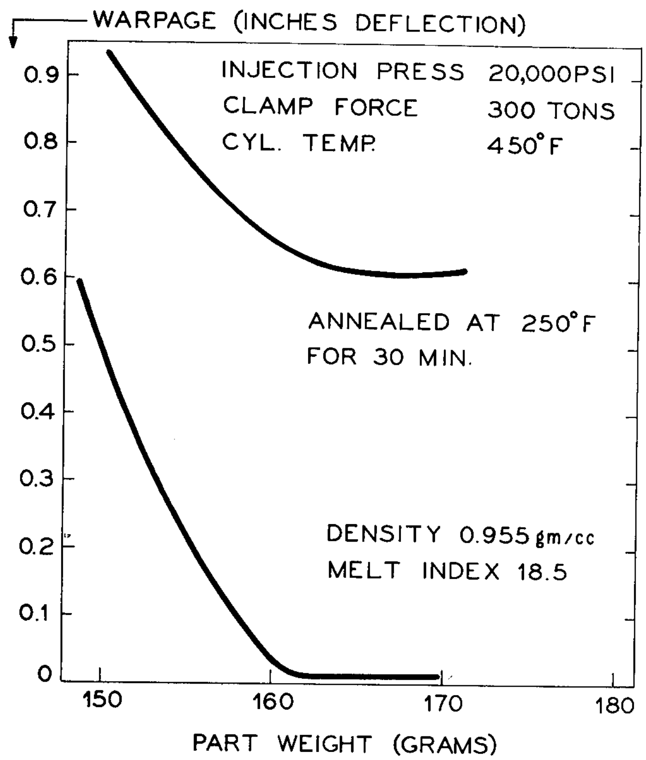

FIGURE 2
EFFECT OF ANNEALING

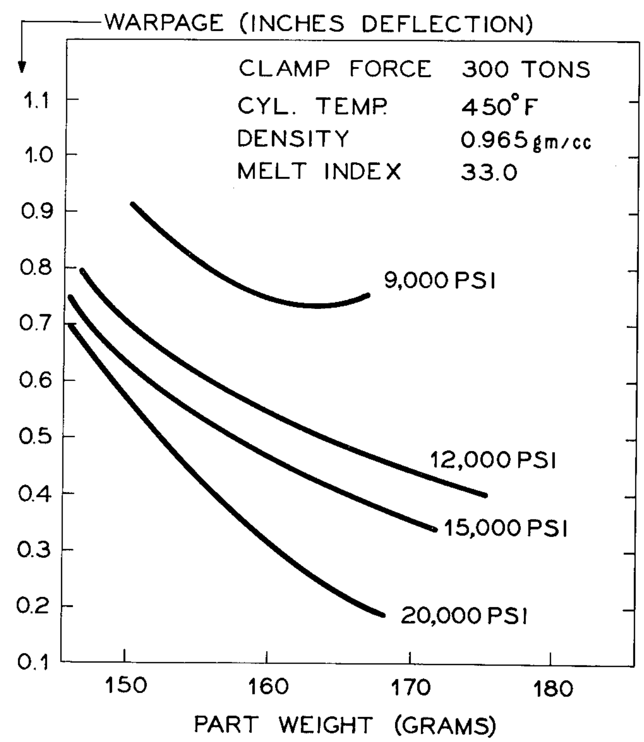

FIGURE 3
INJECTION PRESSURE

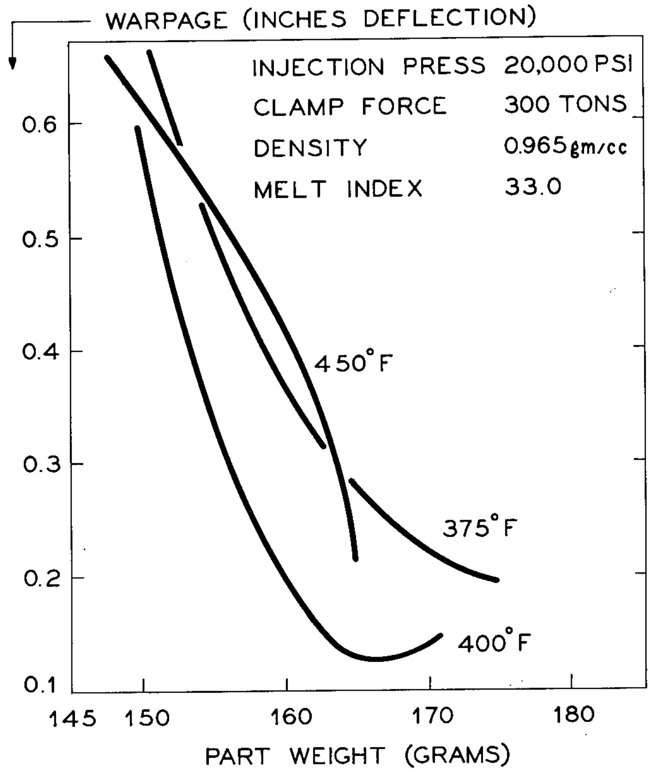

FIGURE 4
PROCESSING TEMPERATURE

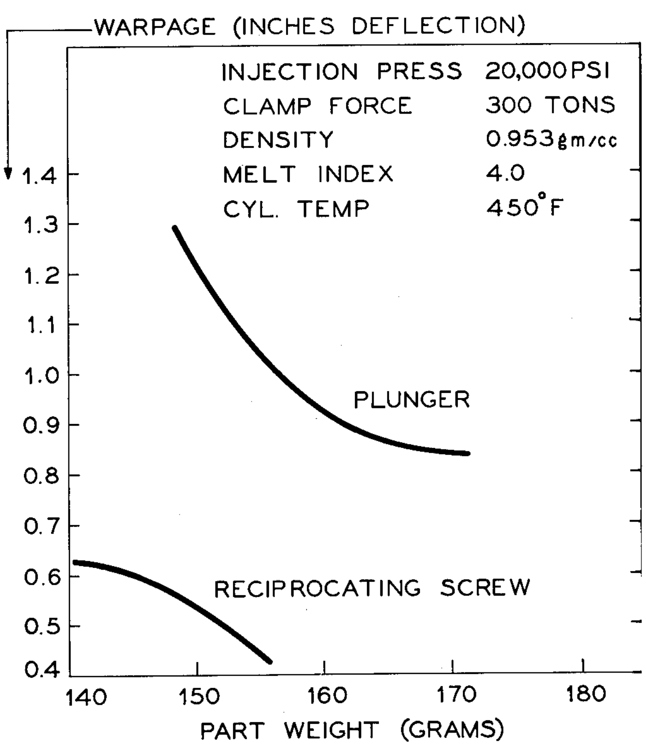

FIGURE 5
EFFECT OF MACHINE TYPE

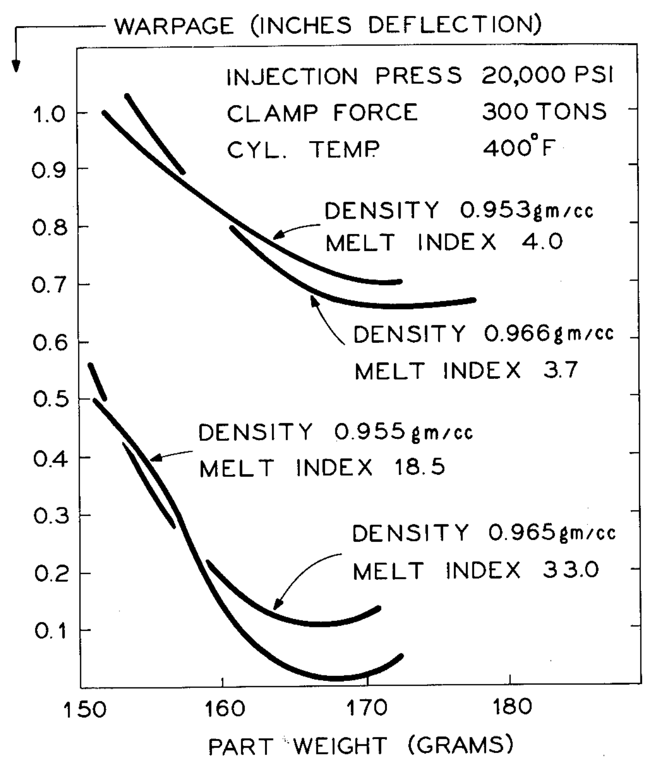

FIGURE 6
RESIN SELECTION

9578-06

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ACRYLONITRILE-BUTADIENE-STYRENE

Eli Schwartz, Manager

KRALASTIC Research & Development

UniRoyal-U. S. Rubber Co.

Naugatuck, Conn.

PROCESSING

A. Injection Molding and the Mooney Viscometer

The most important characteristic of an injection molding compound is its flow. The flow of the material many times determines the thickness and shape of the part, the surface appearance, the weld line strength, the mold design and the cycle time. It is not surprising then that so much has been written about the flow of materials and how it can be measured and controlled.

At an early stage in the development of our ABS compounds we examined traditional flow tests such as minimum fill pressures and melt index. Both these tests were found to be either too time consuming or insufficiently accurate for our purposes. In more recent times we have looked at flow measurements determined by a spiral mold, an extrusion rheometer and a Mooney disc viscometer. We found all of these tools to be useful but I would like to concentrate on our Mooney rheometer work since this machine is easy to run, requires only a small sample and relates remarkably well to the injection molding of ABS parts.

The Mooney machine was invented many years ago by Dr. M. Mooney at the U. S. Rubber Co. Research Laboratories. It was built to measure the viscosity of rubber and it is today the most accepted machine for this purpose. More recently our Plastics Research people* modified the machine to handle rigid polymers. This instrument is shown in Figure 1. The heart of the instrument is a small chamber which contains a rotating disc. The material to be tested is placed inside the chamber. A motor turns the disc at a given rpm causing a shearing torque on the sample, which can then be recorded.

Figures 2, 3 and 4 show how the Mooney measurement relates to spiral mold flow. Figure 2 represents a super flow ABS material, Figure 3 an easy flow ABS and Figure 4 a high heat resistant ABS. As to be expected, the data is considerably different for the various materials but in all cases there is quite good correlation between the Mooney measurement and the spiral flow mold. This is

*Dr. W. E. Wolstenholm and Dr. R. L. Bergen, Jr.

demonstrated again on a master flow curve in Figure 5. Figures 6A, 6B and 6C show the spiral molded parts for those of you who are not familiar with this configuration.

As an injection molder, one might ask, "What practical significance does this have for me". The fact of the matter is that because of this flow measurement, we can in almost every case, determine before your mold is built which of the ABS grades will be suitable for the part you have in mind, and what design changes may have to be made, if any.

B. Extrusion

In the sheet extrusion area one of the most significant developments has been the slotted ring and variable mixing screws. This type of design has allowed us to increase our plasticizing ability and thus improve outputs. These screws are described in Figure 7.

In the extrusion of pipe, the most efficient sizing equipment has been found to be a vacuum sizing tank. This is described in Figure 8.

Dehumifier driers are an excellent investment for all types of extrusion. These drying systems help increase output and improve quality.

C. Calendering

There has been considerable interest lately in the calendering of flexible ABS/PVC sheeting for automotive applications. One of the problems has been the stringent shrinkage and tear strength requirements. A study carried out in the laboratory showed that shrinkage could be kept to a minimum, and uniform tear strength to a maximum when:

1. The calender roll temperatures are as high as possible.
2. The cooling drum is kept as warm as possible.
3. Drawdown is kept to a minimum.

The combined results of this study are outlined in Table I.

MATERIALS

Two new materials which have very recently developed are our anti-static and super-flow compounds. These materials give the processor and end user advantages which have never been available in ABS polymers.

A. Anti-Static, KRALASTIC(R) K-3141

This new grade has an unusual ability to resist dirt and dust pickup. It further has excellent processing characteristics, good impact strength and good surface appearance. It has already started to replace standard ABS grades in those applications where dust pickup is a problem, such as appliances and housings. The properties of this material are outlined in Figure X and a photo-

graph showing the excellent anti-static properties is shown in Figure 9.

SUPER FLOW, KRALASTIC(R) K-3170

This new material has brought an entirely new dimension to the injection moldability of ABS materials. It has been molded in parts where weld lines and flow marks would have made the use of any other ABS compound unsatisfactory. This remarkable flow behavior is described in a capillary rheometer flow curve, Figure 10.

Figure 11 compares the best molding grade of ABS available today versus KRALASTIC(R) K-3170. The difference in viscosity is striking. At a molding temperature of 350°F KRALASTIC(R) K-3170 has a viscosity of 19,000 cps whereas the best molding grade presently available has a viscosity of 33,000 cps, almost twice as much. At 450°F, KRALASTIC(R) K-3170 has a viscosity of 5100 cps, whereas the standard grade has a viscosity of 8600 cps, again almost twice as much.

There is no question that these new ABS compounds described above will allow even a more expanded use of this fine family of engineering plastics.

TABLE I

COMBINED EFFECTS OF ROLL TEMPERATURES, COOLING AND DRAWDOWN

CALENDERING CONDITIONS:	A	B
Temperatures, °F		
Roll 1	280	280
Roll 2	300	310
Roll 3	320	330
Roll 4	320	340
Cooling Water in Drum	Maximum Cooling	No Cooling
Take-Off	40% Drawdown	No Drawdown
Trapezoidal Tear, lbs./.001"		
Against Grain	.760	.836
With Grain	.250	.500
Shrinkage		
Against Grain, %	+8.8	+1.3
With Grain	-15.0	-3.1

TABLE II

PROPERTIES OF KRALASTIC(R) K-3141

Static Reduction	Excellent
Notched Izod Impact Strength, 1/4" @ R.T.	4.0
Rockwell Hardness, "R"	102
Tensile Strength, psi	5600
HDT, Annealed, °F	200
Flow	Excellent

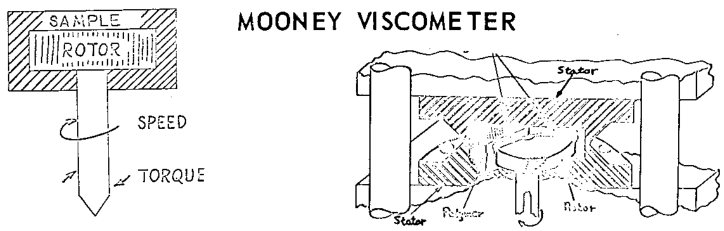

FIGURE 1: Schematic of Mooney Viscometer Chamber

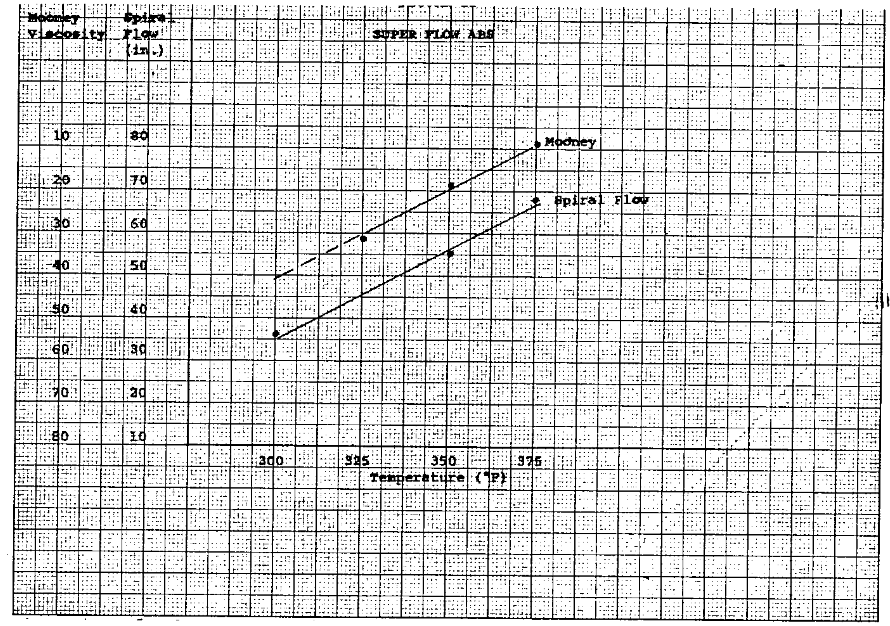

FIGURE 2

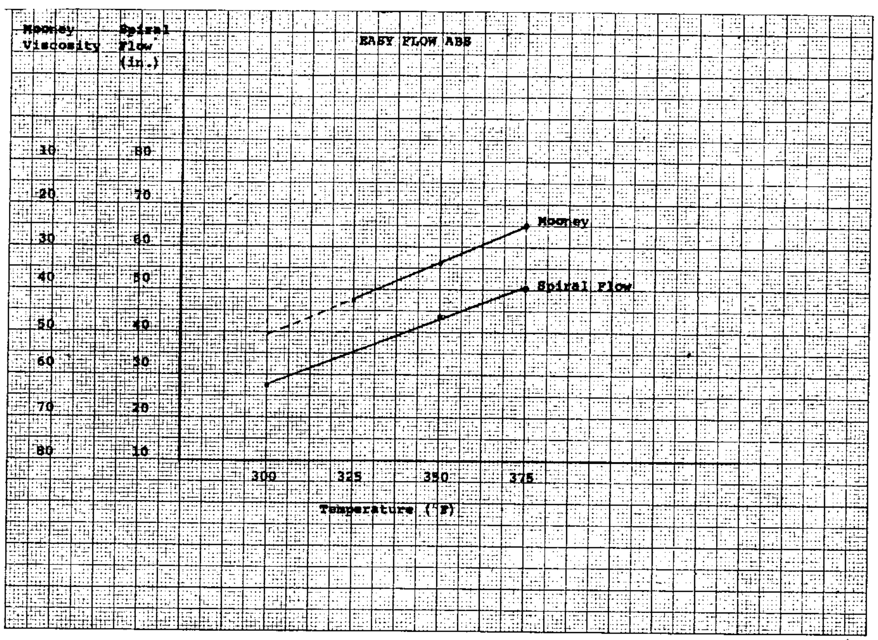

FIGURE 3

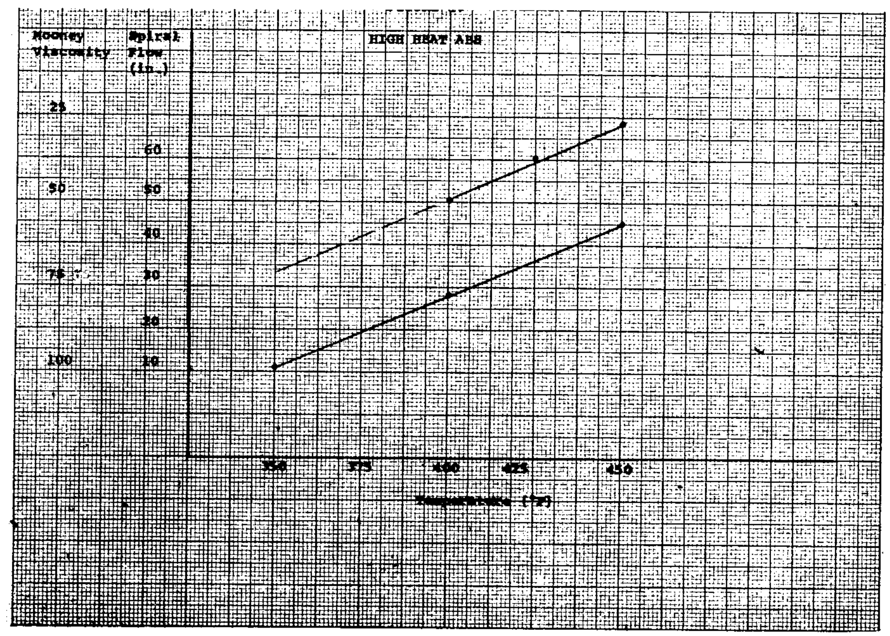

FIGURE 4

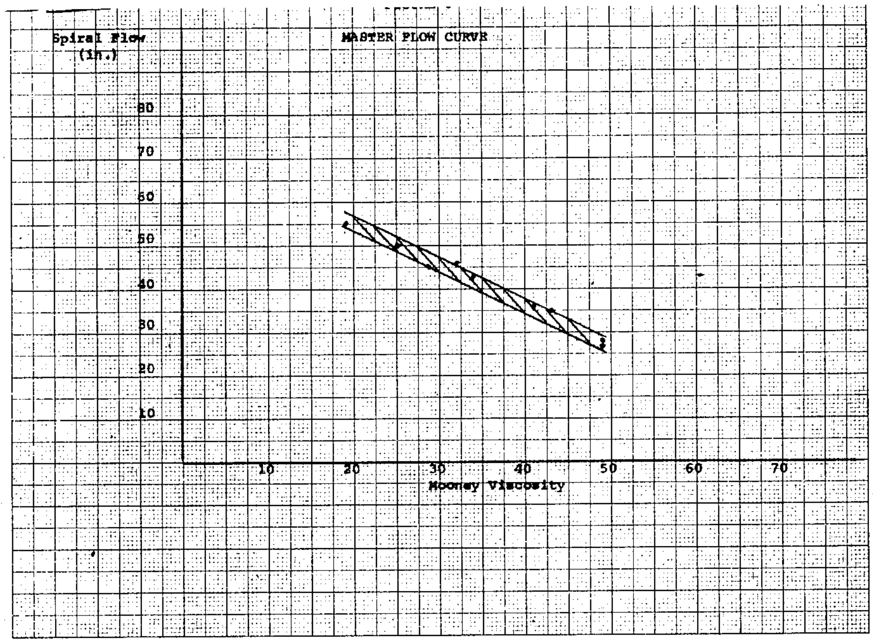

FIGURE 5

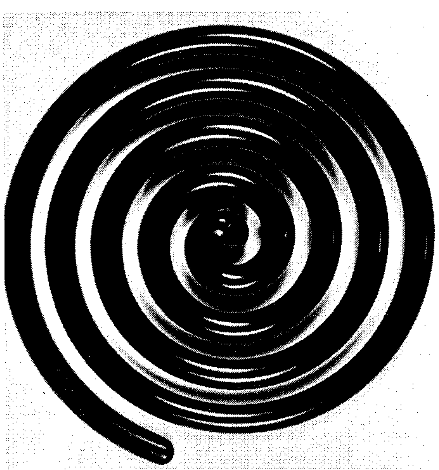

FIGURE 6A

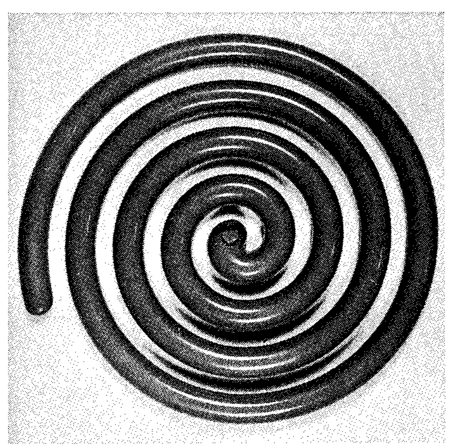

FIGURE 6B

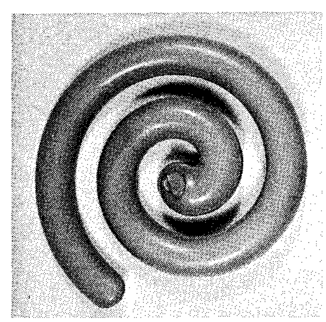

FIGURE 6C

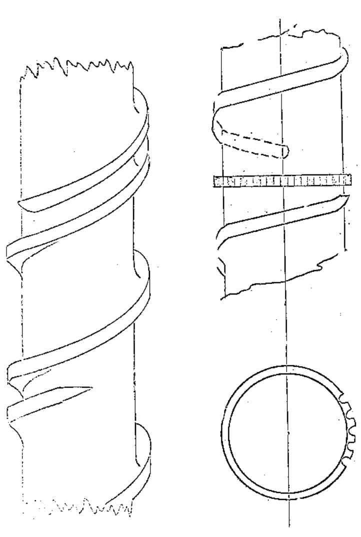

FIGURE 7: Slotted Ring and Variable Mixing Screws

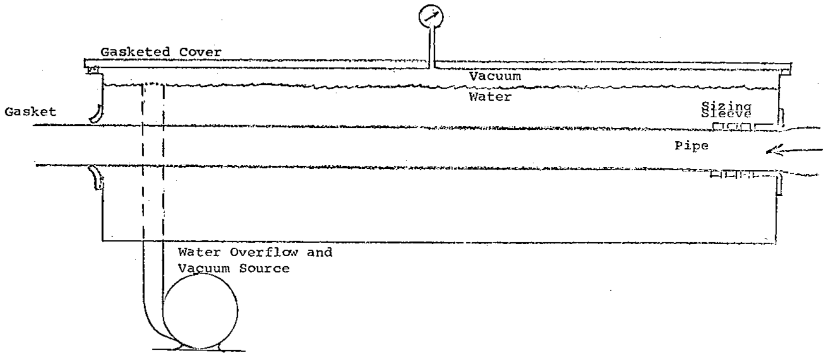

FIGURE 8: Vacuum Sizing Tank

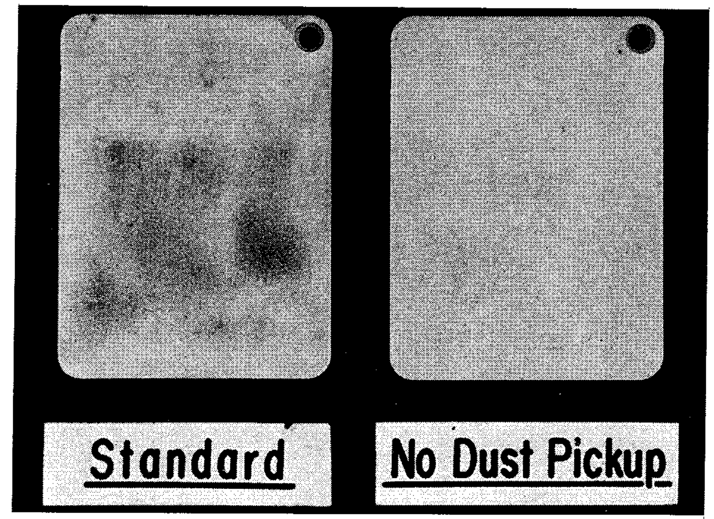

FIGURE 9

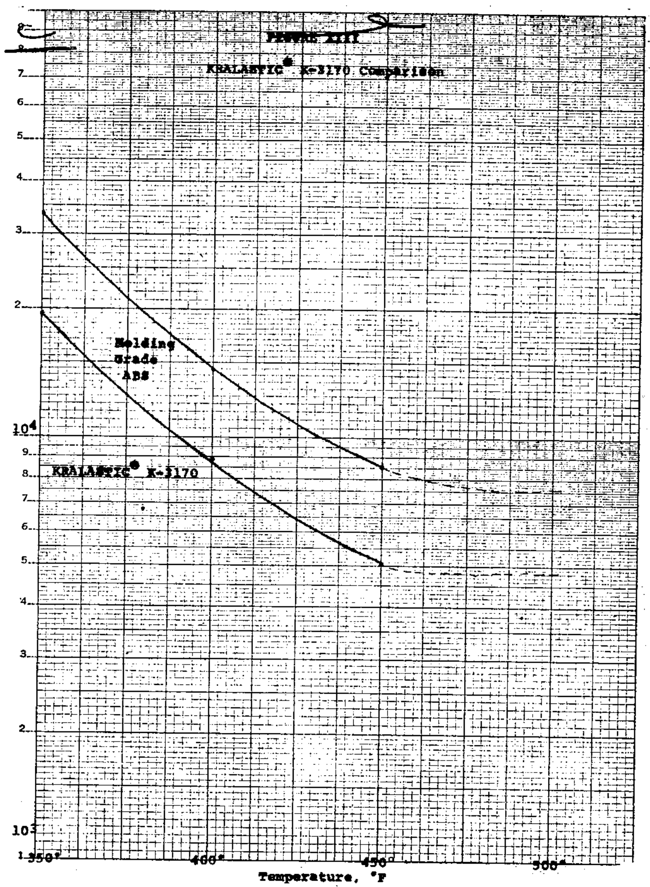

FIGURE 11

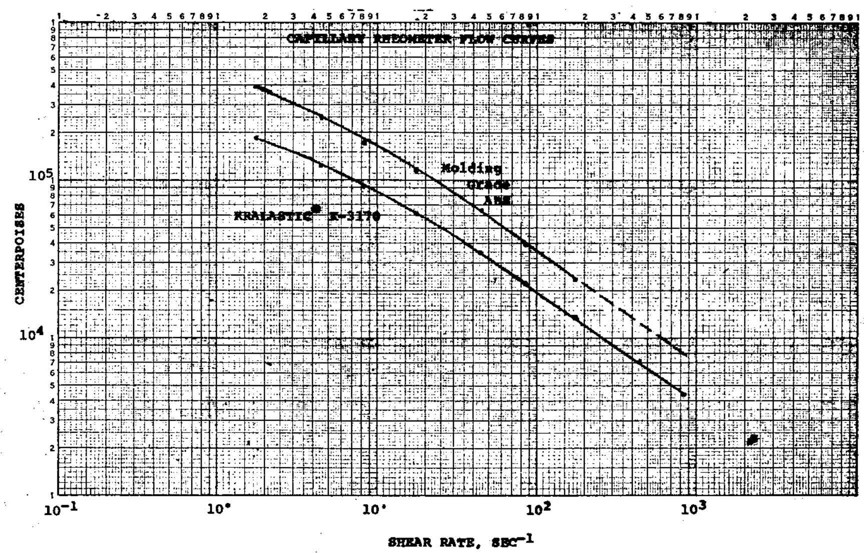

FIGURE 10: Shear Rate, Sec^{-1}

9578.01
48

TECHNIQUES OF INJECTION MOLDING OF RIGID UNPLASTICIZED PVC

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For many years, rigid unplasticized PVC has been a thorn in the side of the injection molder. Only the manufacturers of pipe fittings can look back into the history of injection molded PVC with any degree of accomplishment. Many earlier attempts to secure other applications for PVC were miserable failures. All too often in previous evaluation runs, the materials were heated beyond the decomposition point resulting in the formation of free hydrochloric acid. This, in turn, led to a very serious corrosive attack of the HCl upon the molds and molding equipment.

In addition, the unusually high melt viscosity of PVC prevented the materials from flowing freely within the mold. A fact which further prevented its cosideration as a useful material in most thin-walled injection molded projects.

The picture today, however, has changed decidedly. Recent advancements in the technology of injection molded PVC are rapidly dispelling the old established concepts. Today, it is becoming increasingly more plausible for the injection molder to take advantage of the use of rigid PVC materials. Materials which offer superior properties in impact strength, flame resistance, electrical resistance, stiffness and corrosion resistance.

Factors which have contributed to this re-appraisal of rigid PVC for many applications include:

1. The advent of vastly improved molding equipment such as the reciprocating screw press, a machine that can provide a homogeneous thermal melt condition to the PVC through the internal working of the material.

2. A full realization by the molder that PVC behaves differently from other thermoplastic materials and thus must be treated accordingly. The basic essentials of processing techniques and of mold configuration are constantly being redefined to allow the molder trouble-free production of many new PVC applications.

3. The raw materials suppliers have made appreciable improvement in the processing characteristics and stability of PVC materials to allow the molder more latitude in his production operation. We at Ethyl, for instance, have made substantial progress in developing PVC compounds with melt viscosities appreciably lower than

those normally encountered with the molding of rigid PVC. These materials can be molded into products having quite thin wall sections with little problem of decomposition.

Although recent progress in molding PVC has been most impressive, the pace is expected to pick up as more and more begin to participate and to make their contributions.

MACHINES, TECHNIQUES, MATERIALS

For a better understanding of the industry as it exists today, let us take a closer look at each of these areas, machines, techniques and materials.

A. Injection Molding Machine

The basic requirements of a machine for molding rigid PVC are:

1. It must produce a thermally homogeneous melt without overheating any portion of the material.

2. It does not have any points at which the melt can stagnate at high temperatures and hence, in time, degrade.

3. It does not contain any unnecessary restrictions at which excessive shear heating and degradation of the melt can occur.

4. It must develop sufficiently high pressures to inject the viscous melt into the mold.

The plunger type of injection molding machine is not really suitable for molding rigid PVC. In this type of machine the material is heated entirely by conduction from heating bands located externally around the cylinder. Because of the relatively small range between the melt temperature and decomposition temperature of PVC, the layer of material adjacent to the cylinder wall would decompose long before the remainder of the material would reach the melt temperature.

A rigid PVC compound can be effectively prepared without overheating by the use of a screw plasticizing machine where the intensive mixing action of the screw can provide a thermally homogeneous melt. Best results are obtained by the use of a reciprocating screw machine.

The cylinder of the molding machine is normally made from hardened steel. In some cases an X-alloy liner is used. Both are suitable for use with rigid PVC. Screws are normally made from nitrided steel. The design of standard screws and cylinders is generally suitable for use with rigid PVC but it is necessary for the screw to be fitted with a pointed tip which fits closely into a head of a similar shape.

Most screw tips and heads are made from nitrided steel or stainless steel. In a machine of this type the only point of stagnation is in the space between the screw tip and the head when the screw is fully forward, but any material left in this space at the end of

the injection stroke is stripped away and worked into the next shot by the subsequent action of the screw.

Other desirable features that a machine should possess are:

1. Good temperature control.

2. The torque available on the screw should be sufficient to provide uniform rotation in the 25-50 revolutions per minute range on small and medium sized machines and 15-30 revolutions per minute range on large machines.

3. High injection pressures are required in view of the relatively high viscosity of the melt. Pressures up to 28,000 psi are necessary in a thin-walled product.

4. Facilities for adjustment of screw back pressure, injection speed and hold pressure are necessary.

5. The melt viscosity of PVC is sufficiently high to make the use of check valves at the front of the cylinder or nozzle unnecessary; in fact, undesirable because of the possibility of stagnation and restriction.

6. It is further desirable to modify the nozzle by incorporating a reverse taper. This modification can be used to reduce the cold slug markings on the casting.

B. Fabrication Techniques

The following comments outline the principles to be observed in the molding of rigid PVC. It should be noted that the conditions set forth may have to be modified slightly in order to suit a particular mold or machine.

1. Cylinder Temperature Profile

It is highly desirable to place the gel point of rigid PVC as far forward in the cylinder as possible. This not only greatly minimizes decomposition problems, but also allows any volatiles and gases to escape through the unplasticized pellets at the rear or feed end of the screw. Observance of this technique will result in stronger, less porous products.

In order to obtain such results, the molder should use a very steep temperature profile, progressing from cold at the feed end to hot at the nozzle. Care should be taken not to overload the screw motor by using too low a temperature. Should this occur all temperature settings should be increased to eliminate overload conditions but still the steep temperature profile should be retained.

2. Screw Speed

Because of the high melt viscosity of rigid PVC, it is necessary to use relatively low screw speeds in order to

prevent overheating of the material. For machines with shot sizes up to 30 ounces, screw speeds of from 27-40 rpm will be found suitable. For larger shot sizes, it is advisable to reduce the screw speed to 15-30 rpm. It should be noted that the slower screw speeds generally do not increase the overall cycle time in that the plasticizing cycle is normally shorter than the cooling cycle.

3. Screw Back Pressure

It is generally advisable to operate the screw against back pressure in order to pack material at front of cylinder, displace gases and volatiles which may exist in the semi-melt condition, and provide additionalinternal mixing of the material.

Normal back pressures of from 50-100 psi are generally recommended. However, when the material has outstanding thermal stability, as in the case of some of the newer Ethyl compounds, the back pressure can be increased to values as high as 400 psi to further expel gases and to reduce melt viscosity.

4. Stock Temperatures

The combination of cylinder band heaters, screw rotation speed and back pressure all contribute to the temperature of the stock at the point of entrance into the mold. In the case of many PVC materials, a suitable stock temperature for molding is from 390°F. to 410°F. Many of Ethyl's newer materials easily process at stock temperatures of from 365°F. to 390°F., thus widening the gap between processing temperatures and the temperatures of decomposition.

5. Injection Speed

Because PVC compounds set up rapidly it is important to use a fast fill in injection molding. If restrictions exist in the form of too small a gate or sprue size the injection speed may have to be reduced in order to eliminate frictional burning created by the restriction. This is seen as radial streaks of decomposed material emanating from the gate.

6. Shot Size

The adjustment of the shot size is important as it controls the clearance between the screw tip and the head when the screw is in the fully forward position. The machine should be operated with this clearance at a minimum in order to avoid stagnation of the PVC in the cylinder head. The shot size should be adjusted to the minimum setting consistent with obtaining full moldings.

7. Mold Temperature

A low mold temperature is preferred. The best results of

cycle time and surface finish will be obtained if the mold temperature is approximately at 70°F.

If the filling of the cavity is critical at this low mold temperature as such might be the case with thin wall sectioned moldings, higher mold temperatures can be used. In no case, however, should it be necessary to exceed 160°F.

8. Injection Pressure and Hold Pressure

PVC reacts similarly to other thermoplastic materials insofar as injection pressure and hold pressure. The regulated pressure should be adjusted to the minimum value required to obtain full moldings free of sink marks.

Excessive injection pressure or hold pressure can cause undue molded-in stresses which can contribute to warpage and eventual field failure.

9. Mold Design

Molds for use with rigid PVC should be made to the normal standards for injection molds. It is advisable, however, to have the surface of the mold impression chrome plated. A hard non-porous chrome should be applied directly to the steel. Care should be taken to verify that the steel surface itself is non-porous. Gold plating and nickel also show considerable promise as a plating metal for PVC molds.

In those molds having intricate shut-offs and/or moving core blocks, the molds should be made of stainless steel. Stainless steel #440 is recommended for use with PVC and can be hardened after machining. Other low cost metal molds such as cast aluminum and kirksite can be used with PVC. However, it should be anticipated that the service life of the molds would be limited.

10. Shrinkage of PVC

Shrinkage of PVC generally falls within the range of .003 to .005 in/in.

11. Sprue

When the product is center gated directly from the sprue, the sprue should be as short as possible. The recommended major diameter of the sprue at the intersection of the part should be a minimum of from 175% to 200% of the wall section of the part. The minor diameter at the nozzle should be approximately 75% of the major diameter. It is also very advisable to incorporate a 1/16 radius at the intersection of the sprue and the part. This will be of considerable benefit in eliminating the blush mark around the gate.

In multiple cavity molds the sprue should be approximately 125% of diameter of runners at the major diameter. A large cold slug well should be incorporated at extreme end of sprue.

12. Runners

The mold design should incorporate full round runners ranging in diameter from 1/4 to 5/8" dependent upon the shot size. The runners should be well polished to eliminate frictional decomposition. It is also advisable to incorporate large radii in the runner system where 90° turns are necessary.

13. Gates

In order to allow rapid filling of the mold without danger of frictional decomposition and also to reduce the jetting effect of the initial surge of material into the mold cavity, the gates should be quite large and with a minimum land length. If the product is to be edge gated, the thickness of the gate should be no less than 75% of wall section. The width of the gate should be at least the width of the runner.

A fan gate having a width of 1" or greater would produce even better results than the straight gate just illustrated providing no trimming problems develop.

Three plate molds can be used where the product requires multiple gates. However, the minimum diameter of the gate at the intersection of the minor sprue and the product must be no smaller than .064" in diameter. It should be noted, however, that with small gates of this magnitude, the anticipated length of flow of material into the mold should be reduced.

Submarine gates can also be used but with the same limitations as a three plate mold.

The use of hot runner molds is not recommended for PVC. Generally speaking, the danger of hangup or stagnant material and the usual lack of uniform temperature control throughout the hot runner system preclude the use of this type of mold.

14. Part Design

It is highly recommended that sharp internal corner angles be avoided especially when in close proximity to the gate. Use as large a fillet radius as possible. Venting of PVC mold is particularly important. Trapped gases, when compressed, reach temperatures in excess of the decomposition point of PVC. Thus these gases must be permitted to escape from the mold. Normal mold venting techniques will suffice.

C. PVC Raw Materials

Along with improved equipment and a better understanding of fabrication methods of PVC, the material supplier has also contributed much to the greater acceptance of injection molding of PVC.

As mentioned earlier, the limited use of rigid PVC by the injection molder was due largely to:

1. High viscosities in the melt condition.

2. A narrow range between processing temperature and decomposition point.

3. Lack of adequate short term heat stability to allow fast injection into the mold.

Ethyl Corporation, desirous of making a technical contribution to the PVC industry coincident with their market entrance as a supplier of resins and compounds, recognized the limitations of PVC as an injection molding material. A comprehensive study was initiated to determine the deficiencies, to effect adequate solutions and thereby to provide the molder with more processable PVC materials. We believe that we have come a long way since beginning this program two years ago.

As molders are aware, in earlier years the only PVC molding compounds available were the standard Type I and Type II materials. These had been specifically formulated to satisfy the pipe fitting industry. For these products, good appearance was not necessarily a prerequisite. Likewise, an easy flow material was not of vital importance in view of the very heavy wall sections characteristic of pipe fittings. Thus PVC materials found acceptable by the pipe fitting molders could find little acceptance elsewhere. Ethyl also has a Type I and a Type II pipe fitting compound. Both have NSF approval and carry the highest ratings of burst pressure and impact strength.

In addition, at Ethyl we have developed a series of rigid PVC compounds with easy flow characteristics designed specifically for injection molding. The easy flow features have been built in without loss of strength or resistance to heat. Toughness varies with compound and a wide range of impact strengths is available in this series. The excellent properties of rigid PVC, together with genuinely improved molding characteristics, make these materials obvious candidates for many parts not previously considered for PVC, such as business machine housings, hand tool housings, school and auditorium seating and appliance component parts and for any other product falling within the physical capabilities of PVC.

All of the Ethyl PVC molding compounds will process at temperatures well below those normally associated with injection molding of PVC. As such, the gap between processing temperature and decomposition temperature has been widened. This provides the molder more latitude in production and will reduce the costly maintenance of molds and equipment. As an additional benefit, lower processing temperatures offer the molder a potential reduction in molding cycle. The melt viscosities of Ethyl materials have also been reduced appreciatively; in some compounds as much as one-half that of earlier acceptable compounds. This factor will allow the molder to utilize rigid PVC in many thin-walled, large projected area applications.

In addition to these, all Ethyl molding compounds are highly stabilized to allow rapid filling of the mold.

In order to assist the injection molder and the designer in the use of Ethyl PVC molding materials, we have initiated a flow rating for each of our compounds. This rating we call the flow ratio. It is essentially the result of studies coordinating melt viscosity, set-up characteristics and shear stability of the compounds and then correlating these into actual molding practices. We have been

able to numerically define the length of flow in inches from the gate into a product of any given wall section. Thus, each of our compounds is advertised as having a specific flow ratio such as:

Ethyl #5008 compound has a flow ratio of 93
Ethyl #7008 compound has a flow ratio of 100
Ethyl #7016 compound has a flow ratio of 130
Ethyl #7027 compound has a flow ratio of 145

What does this mean? Simply that Ethyl #7027, for instance, will flow a distance equal to 145 times the given wall section. If the wall section is .100" the anticipated length of flow would be 14-1/2".

This numerical correlation incidentally is derived under constant conditions of mold temperature at 120°F. and an injection pressure of 18,500 psi.

By the use of the flow ratio, the designer can determine the acceptable wall section, the required number and location of gates and basically the specific type of mold to satisfactorily accommodate any PVC molding compound.

As an additional benefit, the flow ratio also serves to aid the molder in selecting the lowest cost PVC compound to adequately satisfy his requirements. For example, if the product has a reasonably heavy wall section and the projected area is small, he could readily use a compound such as Ethyl 5008 which has a flow ratio of only 92. The molder can thereby gain the economy of a lower cost compound.

In summary, with the advances of the last few years, injection molding of rigid PVC is now practical. All participants in the industry have contributed to this, particularly the equipment manufacturer by his development of the reciprocating screw press, the molder and his expanding technology, and the raw materal supplier with vastly improved compounds. Rigid PVC compounds specifically designed for injection molding are now moving into many more sophisticated end products.

We at Ethyl, are rapidly expanding our efforts in behalf of the injection molder. We are sufficiently staffed to provide any technical service necessary to further promote the growth of injection molding of rigid PVC.

9578.08

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POLYVINYLIDENE FLUORIDE - KYNAR

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Polyvinylidene fluoride, known only as a curiosity polymer up to about 1961 has literally "taken off" in a multiplicity of applications. Pipe, rod, sheet, film, tubing, extruded shapes, wire insulation, cable jacketing coatings, molded, machined and otherwise formed parts now effectively service the chemical process, electrical and electronic and coatings industries, providing superior properties and other advantages over previously used or currently competitive materials. KYNAR, produced by Pennsalt Chemicals Corporation in powder, pellet and dispersion form, has now become one of the "regulars".

In order to reach this high degree of success in very short time, even realizing that essentially commercially available equipment can be employed, specific die and mold design, equipment features and controlled conditions must be maintained for processing quality products.

Polyvinylidene fluoride is a highly crystalline polymer, subject to relatively high shrinkage and vulnerable to melt fracture. However, once fabricated into its finished form, is one of the toughest and most versatile, chemical resistance plastics materials available today.

While it is impossible to describe all of the effects on end products quality and performance caused by processing or design variables, we will explain several very important factors.

Let us look at a number of items fabricated entirely from KYNAR or where KYNAR is the most important part of a composite.

Figure 1 shows a 1-1/2" centrifugal pump assembly. The impeller is polyvinylidene fluoride, except for the threaded carbon steel insert by which it is attached to the pump shaft. Housings and covers are metal castings lined with approximately 1/4" thick KYNAR. Originally impellers were made from hard rubber (or synthetic rubber), chemical resistant phenolic or diallyl phthalate molding compounds. Covers and housings were rubber or synthetic rubber lined. Transition to polyvinylidene fluoride was first accomplished by using original rubber molds. The impellers were compression molded. This required a 50 minute cycle dictated by the need to close the heated mold very slowly to avoid air entrapment. Air entrapment on fast close caused burning of the material at the extremities of the vanes (Figure 2). There was no way to vent at these points since the mold was sectioned and hollow for steam heating. Polyvinylidene fluoride has very low thermal conductivity, 0.14 to 0.11 B.T.U./hr-ft-°F (room temperature to 325°F). Therefore, cooling to sufficiently solid state, without deforming on ejection, was slow.

Pump impellers were originally intended for operation at 1750 rpm. However, it was decided there was a need to run at 3500 rpm. At high environmental temperatures this caused separation between the coarsely knurled metal insert and the plastics envelopment in the hub area after only several months operation. Several changes to eliminate this problem were evaluated. Metal fins or vanes were welded to the steel hub (Figure 3), but this caused other problems such as difficulty in filling out the reinforcing webs on the underside of the impeller and even further lengthening the cycle. Several impellers so molded which did appear to be satisfactory after molding, cracked after several hours or days because of the differences in coefficient of thermal expansion between polyvinylidene fluoride and steel. There is no question but that the high shrinkage factor contributed to this problem. Finally, metal anchor lugs were attached to the outside diameter of the still coarsely knurled insert and all inserts were coated with a KYNAR dispersion. The dispersion is an organosol of approximately 45% solids (polyvinylidene fluoride powder) in an 80-20% mixture of dimethyl phthalate and di-isobutyl ketone. The DMP acts as a latent solvent, since there is no true solvent for KYNAR, and the DIBK serves as a wetting agent. To this was added approximately 15% by weight of cobaltic oxide to improve adhesion. The dispersion was applied by spray to a thickness of 0.004" to 0.006" (dry film) and cured at 550°F - 600°F to insure tenacious adhesion. Just prior to molding, coated inserts are heated to approximately the crystalline melting point of the resin (340°F).

Sufficient parts were made in this manner to be tested and justify purchase of a new injection mold. The gate was placed at the center conical location to guarantee uniform filling of the cavity, thus insuring most stress free parts as shown in Figure 4. Cycle time is now less than 15 minutes. Parts molded at too low a melt temperature, low mold temperature and/or low injection pressure show serious signs of melt fracture on surfaces, and are also loaded with stresses. Parts molded at too high melt temperature and mold temperature, prolongs the cycle time, promotes surface blemishes and molded parts are invariably subject to subsequent distortion when exposed to high temperature environment. Because of extremely non-uniform cross sectional thickness, parts, when removed from the mold, must be clamp fixture cooled in draft free location to maintain dimensional stability.

Even before the impellers were proven in the field to be many times better than previously used materials, the housing mold was modified into a transfer type. This, of course, was the least expensive approach. Cycle time for lining the housing was quite long (in excess of two hours). Because of the resin's high shrinkage factor, the lining shrunk and distroted so badly that it was impossible to use the first molded parts. However, since the dispersion coating at the interface worked on the inserts in the impeller, it had to be tried here. It worked out very well. New injection molds were made for both housing and cover, again making use of center gating.

The metal castings are coated with dispersion, cured at elevated temperature and charged hot to the heated mold. As can be seen in Figure 5, the adhesion is excellent. To further insure retention of bond and lessen shrinkage, the resin was filled 25% by weight with superglass fibres (later versions with 25% carbon).

After cutting out the section shown in Figure 6, a metal reinforcing web was welded to the outside of the metal housing without any loss in adhesion. This experiment was conducted to determine if reinforcing webs could be welded on after lining because of the possibility of rating pump at higher pressure. It really had nothing to do with the KYNAR lining. It did prove a very important point - the adhesion of polyvinylidene liner to metal casting using the dispersion coating system. Both pump housing and cover are now molded in less than 15 minute cycles. If dispersion coated castings are not heated to 340°F, inadequate bonding results.

Overheating castings, of course, prolongs the cycle. The core side of the mold must be maintained at 200°F to 220°F. Cycle time was established by inserting thermocouple lead at interface between casting and lining (at the heaviest accessable location) and monitoring temperature. When it reached 200°F, it was safe to open the mold and eject lined casting.

All pump parts are molded using screw injection equipment, which further insures uniformly plasticated melt being delivered to the molds. The injection screw should have tapered delivery end, similar to the type conventionally used with PVC to preclude degradation of material in the valve area (Figure 7). Sliding, positive cut-off designs are also satisfactory, so long as there is no area where molten material can remain dormant. Compression ratio should be in the range of two or three to one. Several metering flights are desirable. A 16/1 or greater L/D ratio is recommended.

KYNAR was selected to be used for spheres in a ball check valve (Figure 8). At first solid balls were transfer molded but this proved to be impractical from a production standpoint. Subsequently two hollow halves were injection molded. This enabled the user to vary weight of the ball within close limits by adding lead or steel shot to the inside of a heat welded assembly. In order to keep secondary operations to a minimum the centrally located gate was placed at the inside diameter. Parts molded employing a cold mold presented a poor surface finish. It was necessary to heat the cavity half of the mold to 250°F to provide a smooth surface. The core half of the mold was maintained at 120°F. Immediately after ejection, components were cold water quenched. It was not necessary to use cooling fixtures since the uniform geometry guaranteed freedom from distortion, even after halves were heat welded together and later subjected to 280°F environment. Figure 9 shows molded hollow ball and another assembly, broken purposely, to show quality of welded joint. Welding is accomplished by first placing components to be joined against a conforming aluminum or other metal surface, heated to 500°F. Contact time will vary with surface area and depth of surface to be softened. Usually 10 to 15 seconds will suffice. This provides 1/32" to 3/64" penetration of apparently molten material. Product design must consider this additional material. Telescoping objects must also be designed to intereference fit. Retention of roundness in hollow ball is sufficiently good to require machining outside diameter only where welding bead is formed. Positive stops in welding clamp fixture account for roundness in all planes. Approximately 1/32" was allowed on each half at parting line of hollow hemispheres to effectively fuse and form an excellent bond.

Many other parts molded using polyvinylidene fluoride, some shown in Figures 10 and 11, also point up the need to use heated molds in most cases 200°F or over to insure bright, smooth surfaces. Invariably, melt temperature between 380°F and 400°F will provide acceptable finish and dimensionally stable parts. If not, melt temperature and/or mold temperature should be increased to realize improvement. It must be understood, however, that increased temperatures will usually increase shrinkage factor. Injection pressures between 15,000 psi and 20,000 psi are required. In spite of KYNAR's high melt viscosity, thin wall parts shown in Figure 12 can be molded with pinpoint or subterranean gates. In this category, however, one must use higher melt temperatures (between 500°F and 550°F). High injection pressures are always required for thin wall parts. This means high clamp pressures and tight fitting mold are needed to preclude flash.

EXTRUSION

Good quality KYNAR extrusions require the use of an extruder having good temperature and speed controls. Barrel should have a well finished inside diameter,

preferably X-alloy lined. Screw should be of the constant pitch (pitch equal to diameter) metering type, 2:1 or 3:1 compression ratio (depending on the product being extruded), at least 20/1 (L/D ratio), well polished-flame hardened flights (small radius on leading edge - large radius on trailing edge), round or rounded cone nosed, made from a good grade of tool steel (SAE 4130) and flash-industrial hard chrome plated. There can be from three and one-half to six metering flights with depth of flights ranging from 0.050" (for low delivery products such as wire insulation or thin wall tubing) to 0.090" (for heavy delivery products such as solid rod, pipe, sheeting, etc.) per inch of screw diameter (up to 3" diameter). Feed section may have from two to four constant depth flights. Transition (compression) section shall be gradual. Flight depth must decrease uniformly between feed and metering sections. Abrupt transition type screw designs are detrimental to the quality of KYNAR extruded products. A pressure gage, preferably one of the newer type transducers, should constantly monitor pressure. Such pressure indicating or recording devices can be positioned at the end of the barrel, in an adapter between barrel and die or in die proper, as long as mounting inside does not disrupt or alter the flow of molten material. Recessed or protruding areas large enough to cause "hang-up" can easily become sites for discoloration and degradation of the molten polymer. Streamline all areas of resin flow as much as possible from the time the pellets enter the extruder until the molten polymer leaves the exit of the die.

Extreme care must be exercised when extruding KYNAR. The need for exacting control is prompted by three factors:

1. KYNAR has a high thermal coefficient of expansion (8.5×10^{-5}).

2. KYNAR has a high thermal insulation value.

3. KYNAR has very high shrinkage 0.020"/in. to 0.030"/in.

In order to compensate for these conditions, it is normally necessary to extrude at the lowest possible temperature at which a homogeneous melt is apparent. Low barrel temperatures also help keep cooling and distortion problems to a minimum.

An example of these factors would be best shown be describing the extrusion of rod:

Making use of a 2" extruder, having a 24/1 (L/D ratio), with a three-to-one compression ratio, gradual transition, five metering flight (0.160" depth of flights in metering section) screw, starting temperature of all four zones as well as gate and die adapter should be set at 360°F (182°C). Die adapter is specifically necked down to a diameter smaller than the finished diameter of rod being extruded (approximately 70% of total die opening is a good starting figure). Transition from extruder diameter to necked down area and return to extrusion die size should be via 10° to 15° angle. Normally a breaker plate is also used. Both breaker plate and necked down adapter primarily provide uniform back pressure. Providing the barrel is empty screw can be rotated at 10 to 12 rpm until barrel and die are filled with material. Forming die land length should be at least four-to-one (based on diameter of finished rod). Cooling die should be same diameter as forming die. Both must be highly polished and preferably flash hard chrome plated. Cooling die should be adjustable for cooling length and approximately twelve times as long as the diameter dimension.

Once the die is filled and rod is being formed, heats for all zones of extruder should be lowered to 340°F (171°C). Feed zone can be brought down to

330°F (165°C). Gate and adapter should be reset at from 350°F (177°C) to 380°F (193°C) to provide best surface and freedom from voids (vacuum voids formed by shrinkage) in finished product. A caterpillar type take-off (or some other adequate type) having high driving and braking power must be used so that take-off rate is at least 20% slower than normal feed rate. In any event, both extruder and take-off equipment must be securely fastened to floor to prevent slippage. Otherwise, serious vacuum voids and distortion will result (Figure 13). Normally rod diameter should be slightly larger than cooling die. This means that core area is still molten but under pressure. Only sufficient pressure to preclude vacuum voids from forming should be used. Otherwise highly stressed areas will exist which could be cause for distortion of parts subsequently machined from such product. Operating pressures will vary from 2000 psi to 5000 psi governed primarily by rod diameter, but also affected by temperature of melt cooling rate. Take-off should be placed as close to the end of the cooling die as possible and rod should preferably be passed through temperature controlled bath immediately after leaving take-off. The latter will help minimize stresses and provide laterally undeformed rod. Rod coming from cooling trough should be supported in "V" channel (or equivalent) to desired cut-off length. Cut length should be immediately stored in fully supported straight position.

Three most serious faults occur when the foregoing is not observed.

1. Molten resin breaks through congealed skin. This can happen as a result of taking away too fast and sufficiently heavy skin not being formed in adequate length of cooling die or too high an internal pressure.

2. Poor surface finish and distortion are normally caused by too fast take-off and inadequate pressure.

3. Vacuum voids result from too low pressure, too fast take-off, inadequate cooling in cooling die, or melt temperature too high.

Since indicating instruments on extruders do not always show the correct temperature for a given position because of thermocouple location or some other reason (even though instrument itself is accurate), all temperatures given are strictly relative. Whenever possible melt temperature and zone temperatures should be double checked with auxiliary equipment.

Film, especially the thin gage variety, requires higher barrel and die temperature than heavy cross section products (Figure 14). Normal extruder temperature would be around 500°F (260°C). Die temperature will also run 500°F (260°C) to 550°F (288°C). In fact, die lip temperature can run as high as 800°F (428°C) to prevent melt fracture. When extrudate leaves die lips it should be fed as directly as possible between the top two rolls of a three roll heat controlled stack of rolls. Top two rolls should be set at 280°F (138°C) to 300°F (149°C) and bottom roll at approximately 250°F (121°C). A slight bead must be maintained between top two rolls. Take-up should only provide sufficient tension to prevent wrinkling. Otherwise, uncontrollable machine direction orientation will take place causing serious post shrinkage problems.

Polyvinylidene fluoride is used in wire insulation and cable jacketing applications, primarily because of its general toughness (Figure 15). Conventional cross head dies proved relatively inefficient. A valve type cross head die (Figure 16) was especially designed and patented by Pennsalt engineers to deliver a better converted polymer melt and relatively stress free, very smooth insulation at good production rates. Properly sized extruders are required for satisfactory

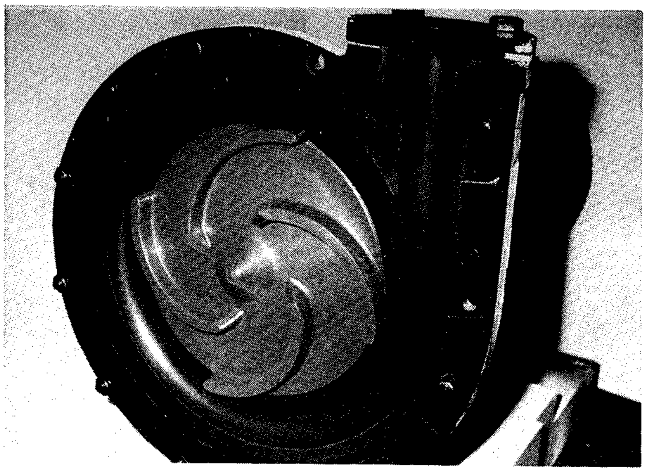


FIGURE 1: Centrifugal Pump Assembly Kynar Lined. Impeller is solid Kynar except for carbon steel shaft insert. Part of cover has been removed to show more detail.

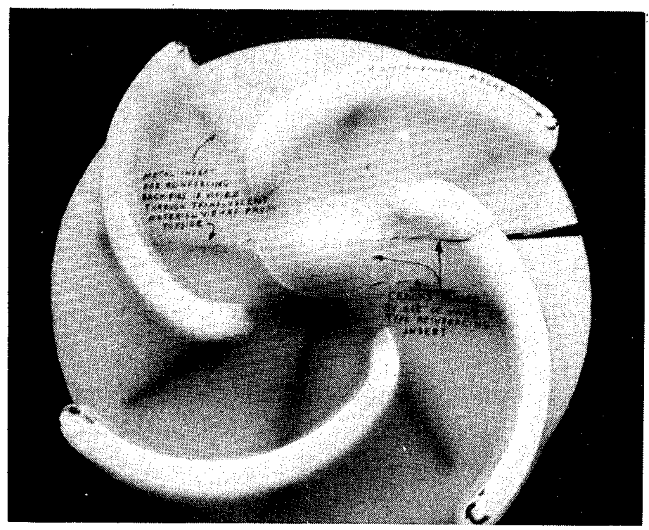


FIGURE 2: Top side of polyvinylidene fluoride pump impeller shows cracking as a result of differential in thermal expansion coefficient between P.V.F.$_2$ and steel. Also evident are burn marks at extremities of vanes caused by air entrapment on fast close cycle.

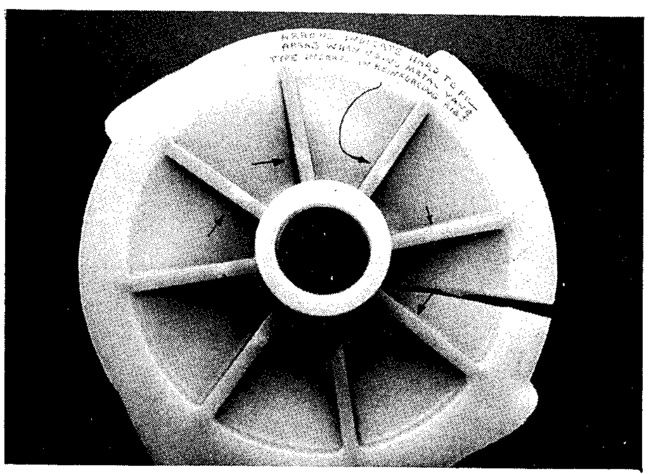


FIGURE 3: Underside of pump impeller molded using polyvinylidene fluoride. Photo shows metal fins attached to shaft insert, originally intended to reinforce ribs. Use of vane inserts caused hard-to-fill areas indicated by arrows.

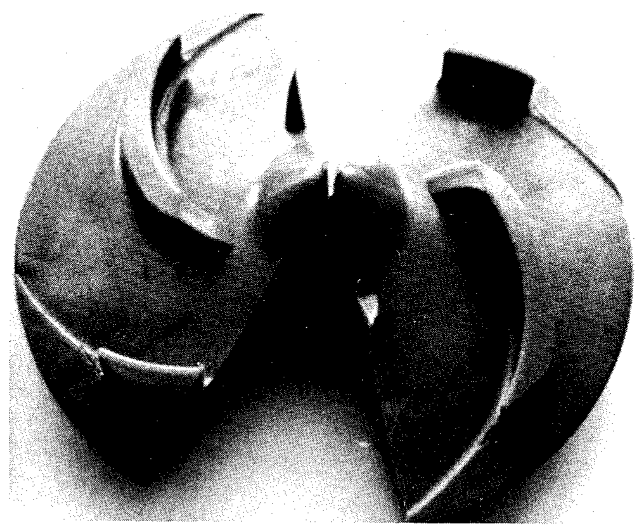


FIGURE 4: Cut away section of P.V.F.$_2$ pump impeller clearly shows knurled dispersion coated metal insert. Part is gated at top of conical shape for uniform fill and minimal finishing operations.

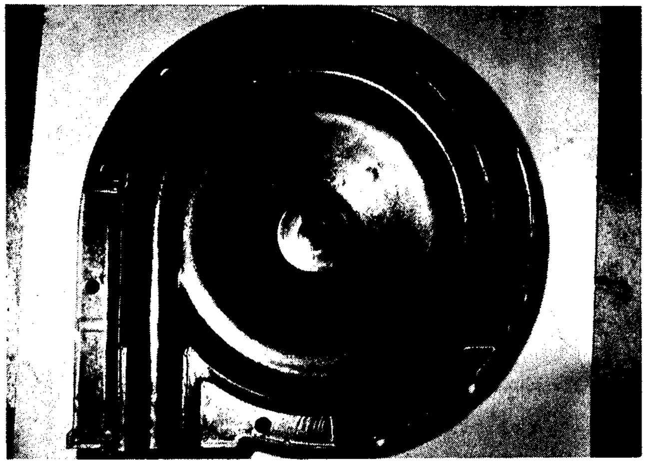


FIGURE 5: View of 1-1/2" centrifugal pump housing lined with Kynar.

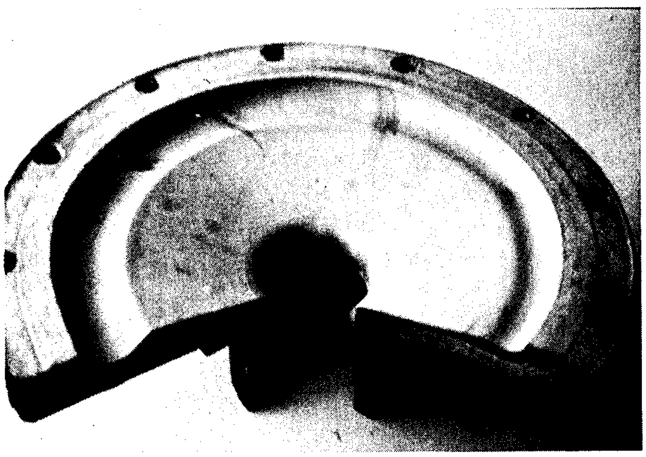


FIGURE 6: Cut away view of 1-1/2" centrifugal pump housing shows how tenacious bond is affected between metal base and approximately 1/4" thick P.V.F.$_2$ injection molded lining.

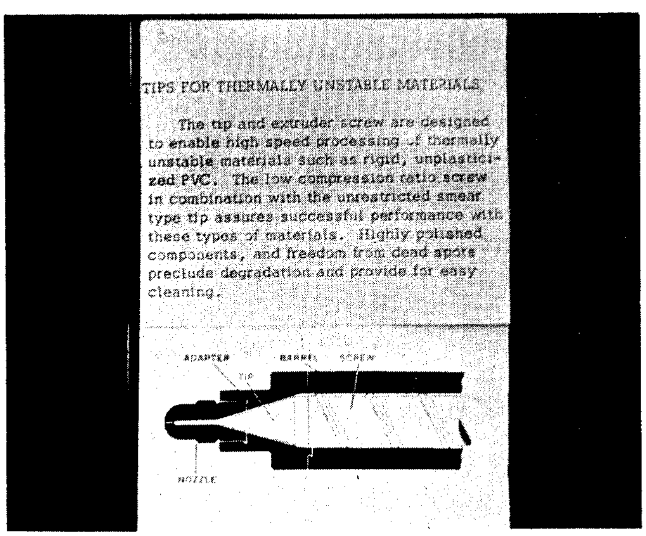


FIGURE 7: Typical screw design used for injection molding polyvinylidene fluoride.

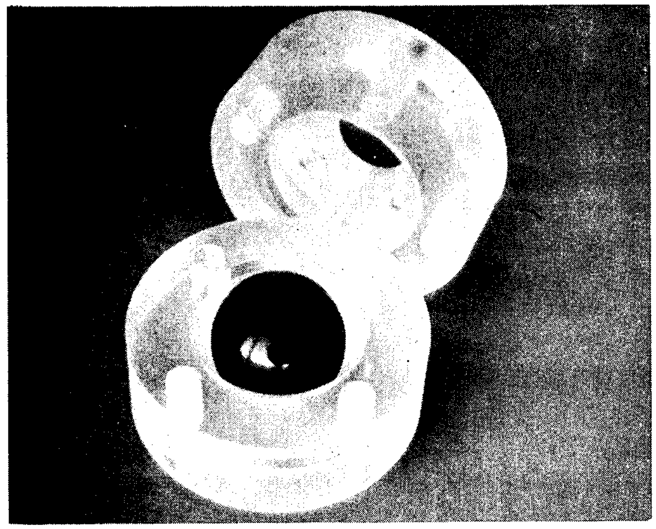


FIGURE 8: Transparent model of ball check valve here shows Kynar molded ball used for its toughness and chemical resistance.

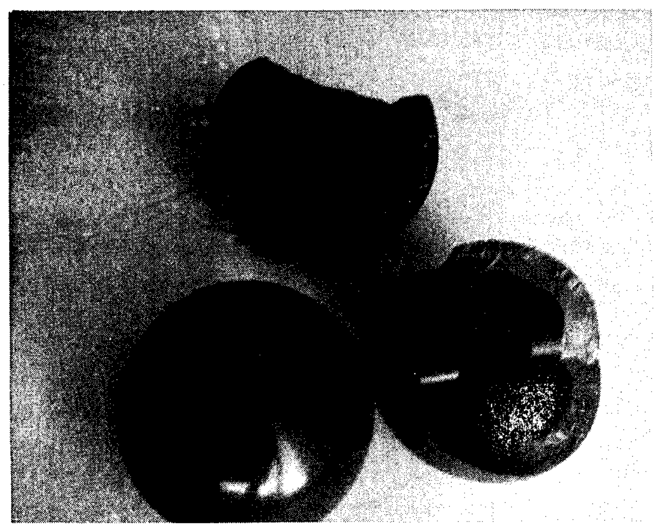


FIGURE 9: Hollow spheres, molded using polyvinylidene fluoride for critical chemical service check valve. View shows assembled ball and broken section exemplifies unusually strong joint formed by merely heating surfaces to be joined to a depth of approximately 1/32" before clamping together.

results. This cross head die has a 14° angle as does both valve faces. The wire supporting mandrel uses a 12° angle. Wire pilot tube, supporting mandrel and valve all individually adjustable to cover a wide range of wire sizes and extrusion conditions. Small extruders, one inch to 1-1/2" diameter having 20/1 (L/D) or better, compression ratio of two-to-one and gradual transition metering type screw are necessary. Pressures at the end of the screw will vary between 4,000 psi and 9,500 psi depending on the size and other factors of the extruder. Pressures should be measured using a transducer rather than a Bordon type pressure gage, located at the end of the barrel or in the die adapter (flush mounted to preclude pick-up). Gages requiring silicone grease can cause degradation of polyvinylidene fluoride and must not be used. Handling of small diameter wire (30 gage and under) requires extreme care under production condition. Exacting tension control of pay-off and take-up is necessary and may require some modification to existing equipment to achieve most exacting trouble-free control.

Much the same as in extrusion of film, higher temperatures are required. Extruder barrel temperatures range from 450°F (235°C) in the feed section to 500°F (260°C) in the last section and die adapter area. Body of the die should be 500°F to 550°F (260°C to 290°C). The forming die tip must be high - 780°F to 820°F (415°C to 435°C) to preclude melt fracture and present extremely smooth surface. This high heat acts the same as fine polishing glass. Since even identical extruders of the same manufacture can vary in temperature control settings as well as in other respects, all of these recommendations are relative and individual operations must be positively defined for any particular equipment. It is suggested that sufficiently safe low temperatures be used as a starting point. Temperatures, extruder speed and wire line speeds must be accelerated slowly until best quality at maximum output is reached.

When closing down any extrusion operation it is necessary to first lower temperatures on die and then on extruder. When extruder temperatures reach 400°F (204°C) feed of material may be stopped. It is highly recommended that all dies be cleaned while still hot. The molten polymer, while extremely viscous, strips off easily. It is also highly recommended that extruder be allowed to run until resin stops flowing from open end of extruder. At this time only very slight traces of resin band can be found on trailing edges of first several flights (if at all). Never stop extruder before lowering temperatures. If flow of material has to be stopped for more than 15 minutes, all temperatures should be lowered to 400°F (209°C). Decomposition products are hydrogen, fluoride and carbon. Not only for safety, but in the best general interests of employees, precautions such as use of exhaust duct, etc., should be taken to prevent inhalation of HF should inadvertant decomposition take place. This is standard practiceregardless of material being used in well engineered shops. A general but deep darkening trend in the material indicates the advent of decomposition. This will enable one to see the effects of slight decomposition long before they can be measured physically. Dark streaks or spots in the melt usually indicate a local decomposition caused by hold-up of resin in some part of the equipment. One can easily detect the source of trouble by disassembling die components in sequence beginning at the outlet end of the die. Never attempt to remove polymer from metal parts by burning or exposure to decomposition temperature. This only increases the adhesion of KYNAR to the metal. If proper temperatures are used the material strips off easily.

While seemingly foreign to normal plastics processing problems, the use of polyvinylidene fluoride as a coating for metal in organosol type finishes for anti-corrosion, durability and beauty nevertheless requires rather exacting control. Previously, polyvinylidene fluoride dispersions were basically described as approximately 45% solids in an 80% D.M.P. - 20% D.I.B.K. solvent system. Many variations of solvent, filler, pigment, etc., are possible to meet end use requirements.

Several examples of the use of polyvinylidene fluoride dispersion in combination with the melt processable polymer were described. There are applications, however, which require chemical resistance combined with good mechanical properties but are of such a size or shape that conventional melt processable methods of fabrication cannot be conveniently employed. Such is the case of chemical process vessels and related equipment. Building materials including beams, extruded, rolled and/or otherwise formed shapes also fit this category. These products when coated, require extreme resistance to chemical vapors, U.V. and general weathering resistance, and at the same time color compatibility with surrounding areas.

Specially processed polyvinylidene fluoride powders have been combined with solvents and formulated to provide excellent chemical and weathering protection to many structures. A Pennsalt warehouse in Calvert City, Kentucky (Figure 17) which is located in the middle of an industrial chemical complex sports KYNAR 500 resin formulated finish. It was reverse roller coated applied over galvanized steel panels used for the siding and roof. The doors were spray coated. Previously used materials did not stand up in this environment. Basically the formulations had to be modified to meet both spray and roller coating requirements. Colors used were light blue and off-white. Processing factors which had to be carefully controlled were dispersion viscosity, coating thickness, and time and temperature exposure for curing. Too high heat or excessive air exhaust would cause blistering. Too low a temperature or insufficient and proper solvent system would cause mud cracking.

One of the applicators of KYNAR 500 based formulations feels so strongly about the durability and beauty of this finish that he chose to use it on the entrance to his building (Figure 18). Colors are light green and off-white. Corrugation, embossing and forming of panels was done after the finish had been cured, further evidence of superior mechanical properties.

Sears' store in Austin, Minn. designed by Gerrish & Associates of Minneapolis (Figure 19) displays a special green color for the mansard roof. Porcelain enamel offered the architect a reasonably long life finish but also had a very high price tag. Baked enamel would have been less costly but is vulnerable to fading and chalking by weather exposure. By using polyvinylidene fluoride based formulation it was possible to obtain a long life color at a reasonable price.

Normally deep blue conventional finishes for architectural structures are very prone to fade and chalk after only several months of outdoor exposure. Figure 20 shows the National Can Corporation building in Loves Park, Illinois. It was designed and constructed by William F. Lotz Co. of Philadelphia. Here the owner chose a particularly deep blue color which is partial to chalking and fading. Accelerated Dew Point Weatherometer test results indicate that the KYNAR 500 finish will retain its original color without any maintenance even in the chemical industrial fume environment.

Kahn & Jacobs of New York City needed a particular tan color which would be compatible with the fieldstone and masonry on the B. Altman Store in St. Davids, Pa. (Figure 21). The aluminum louvers were coated with polyvinylidene fluoride base finish. Originally adhesion was not satisfactory. Formulation changes were made so that it was possible to obtain a long life adequately adhering finish that is esthetically pleasing. These panels and extrusions were sprayed using electrostatic spraying equipment.

Public Service of Oklahoma needed a finish for their power plant which would stand the abuse of hot sun and resist abrasion by blowing sand. Polyvinylidene fluoride base coating measured up to all design criteria (Figure 22). Once again panels were formed after coating was cured on metal.

FIGURE 10: Parts injection molded using polyvinylidene fluoride include a small pump impeller, valve bodies, pipe coupling, permeability cup, coil form and straps used for wire harnesses.

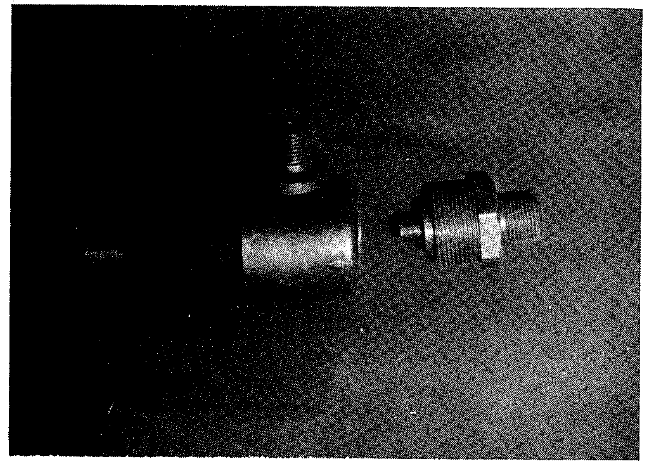


FIGURE 11: Small core separater components injection molded from Kynar.

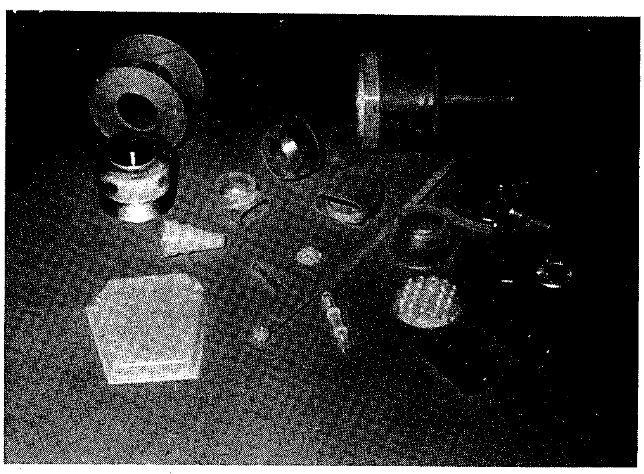


FIGURE 12: Thin wall parts injection molded using polyvinylidene fluoride. Coil forms, bobbins, potting boots, and straps used for wire harnesses shown were molded using conventional, subterranean and pinpoint gating. Relative size is evident by comparison with coin.

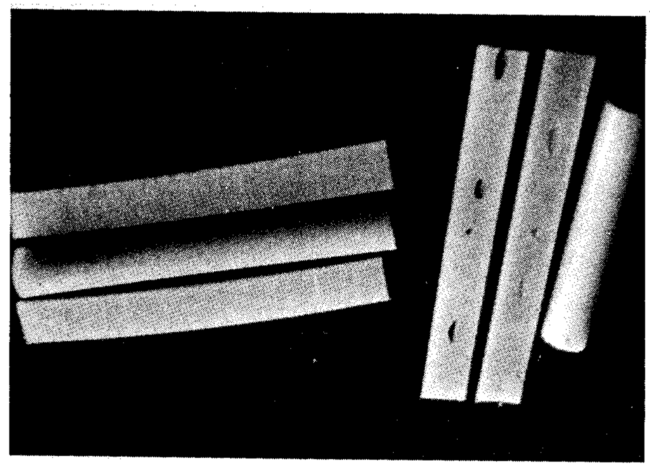


FIGURE 13: Polyvinylidene fluoride 1-1/4" diameter rod sections show vacuum voids caused by high melt temperature, low pressure, etc., next to void-free section extruded under properly controlled conditions.

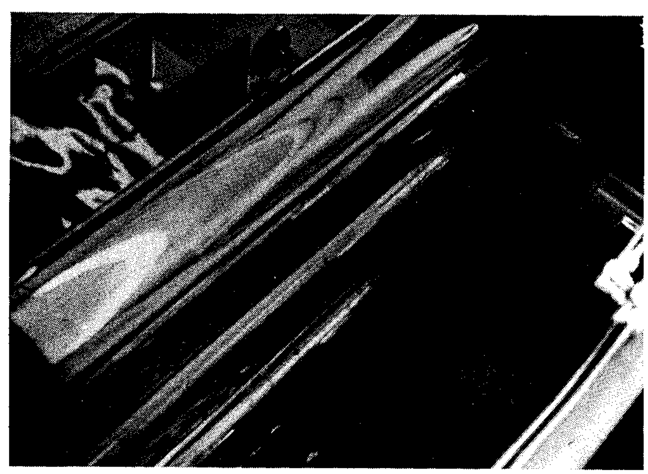


FIGURE 14: General view of slit film die extrusion of Kynar. Relationship of die lips to stack roll position was purposely altered in photo. Normally die is set as closely as possible to stack roll.

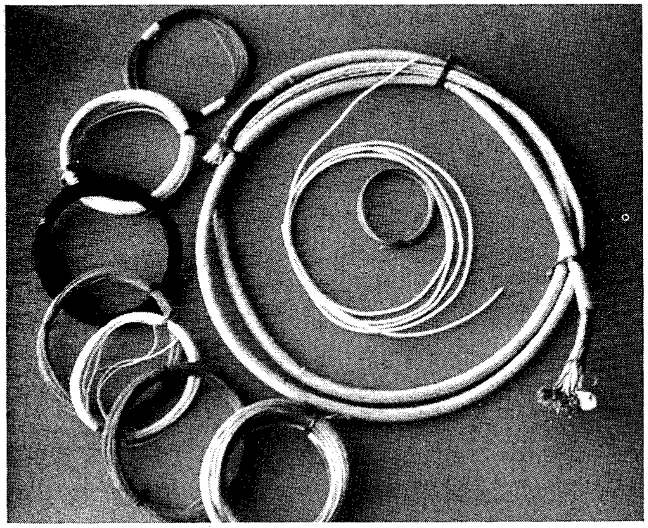


FIGURE 15: Various types of wire constructions using polyvinylidene fluoride as primary insulation or jacket.

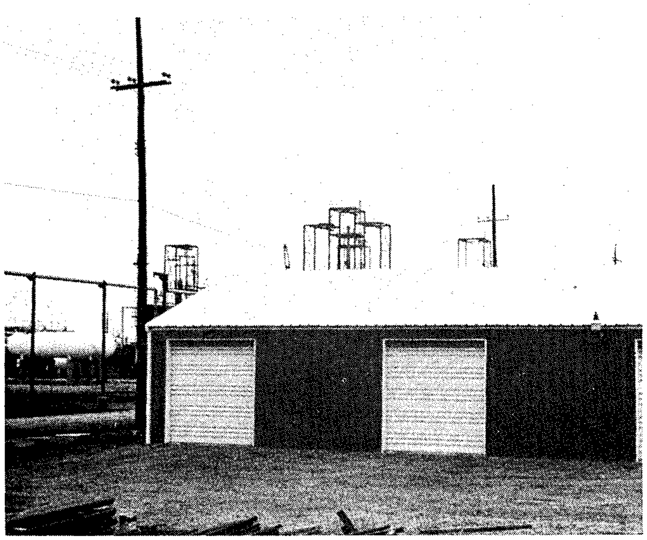
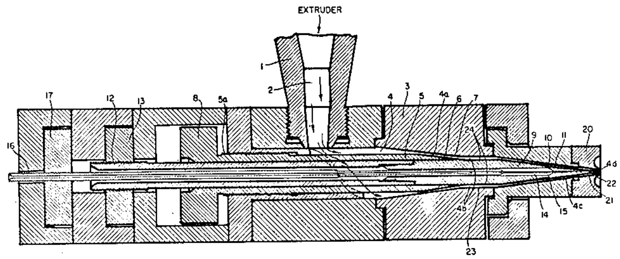


FIGURE 17: Pennsalt Chemicals Corporation warehouse in the middle of an industrial chemical complex at Calvert City, Kentucky shows long lasting resistance qualities of Kynar 500.

DIAGRAM OF CROSS HEAD DIE



KEY

1 - ADAPTOR TO THE EXTRUDER
2 - PASSAGE OF MELT
3 - CROSSHEAD DIE BODY
4 - ANNULAR MELT FLOW ORIFICE (4A, 4B, 4C, 4D)
5 - VALVING MANDREL
6 - TAPERED VALVING MANDREL END
7 - SEAT OF THE VALVE
8 - VALVING MANDREL ADJUSTING NUT
9 - SECOND VALVING MEANS; MANDREL
10 - FRUSTO - CONICALLY SHAPED TAPERED END
11 - SECOND FRUSTO - CONICAL SEAT
12 - THREADED PORTION
13 - EXTERNAL ADJUSTING KNOB
14 - CYLINDRICAL OPENING
15 - THIRD VALVING MEANS; MANDREL FORM OF HOLLOW SHAFT
16 - THREADED SECTION AT REAR OF DIE BODY
17 - ADJUSTING KNOB THREADED AT CENTER TO ROTATE AROUND #15
20 - SHAPING DIE ATTACHED AT FORWARD END
21 - FRUSTO - CONICAL CAVITY
22 - CYLINDRICAL LAND
23 - CYLINDRICAL CAVITY
24 - CYLINDRICAL PORTION

FIGURE 16: Adjustable valve-in-head die designed by Pennsalt engineers to provide most economical, fault-free extrusion of Kynar insulation.

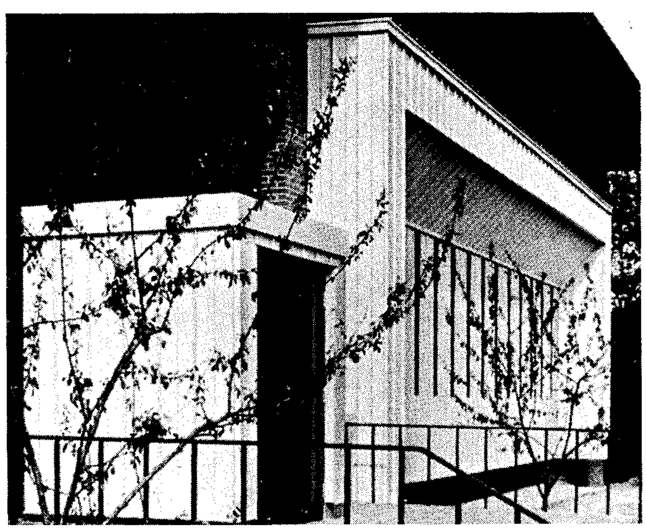


FIGURE 18: Front entrance to Elwin G. Smith Building in Pittsburgh industrial area. Panels coated with Kynar prior to being formed.

FIGURE 19: Special green color for mansard roof on this Sears store in Austin, Minnesota and other paneling is polyvinylidene base finish.

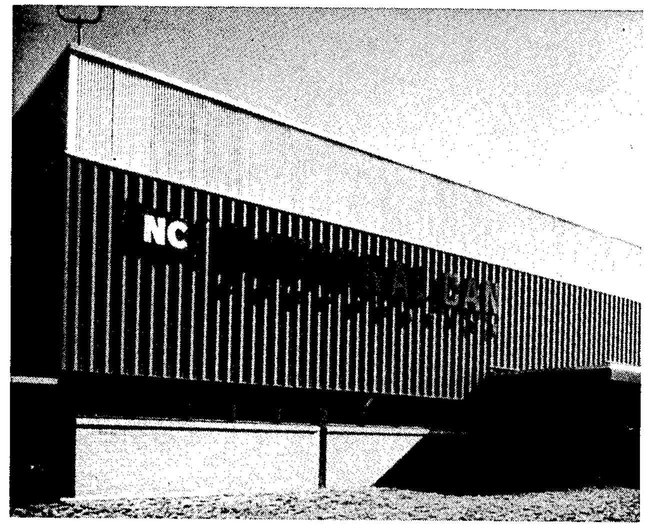


FIGURE 20: Dark blue Kynar base finish promises long maintenance free service life on this National Can Corporation building in Loves Park, Illinois.

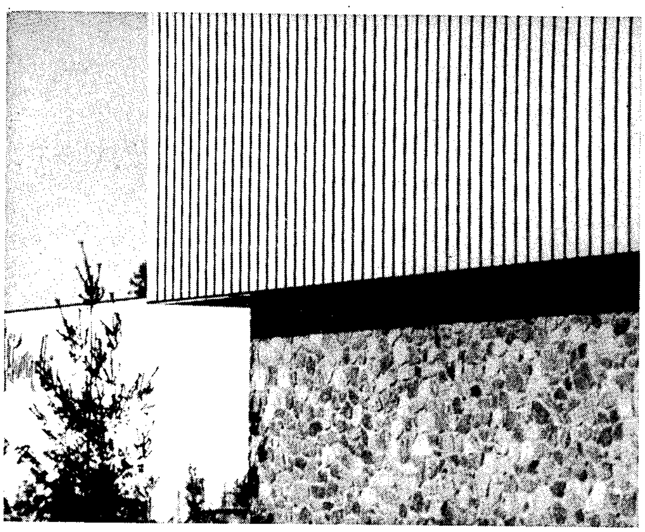


FIGURE 21: Electrostatically spray applied polyvinylidene fluoride base finish insures long lasting well bonded tan finish to panels on B. Altman store in St. Davids, Pennsylvania.

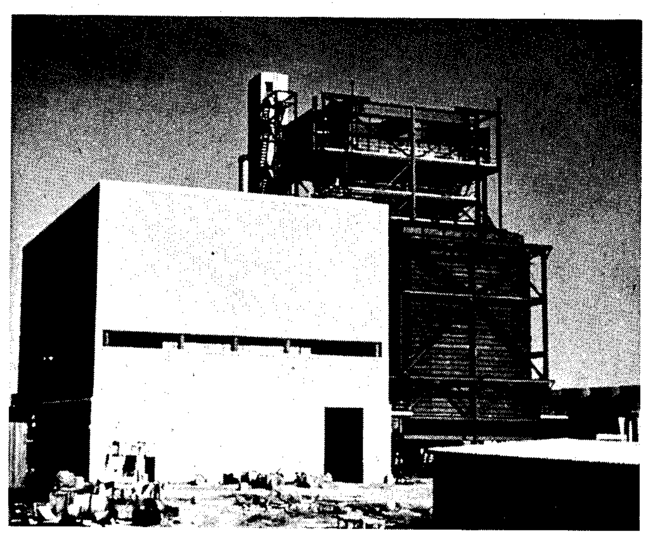


FIGURE 22: Blowing sand and heat dictated use of Kynar base finish for this power plant for Public Service of Oklahoma.

TECHNICAL ADVANCES IN AUTOMATIC MOLDING

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INTRODUCTION

Technical advances in equipment for molding thermosets have been rapid over the past six years, and during the past three years there has been a real breakthrough in the design of this equipment. The techniques of injection molding and extrusion, until now thought suitable only for thermoplastic materials, have been successfully adapted to the thermosetting molding process, on a commercial basis. The highlights of these developments will be examined below.

The oldest of the thermosets dates back to 1910 when Dr. Leo H. Baekeland first developed phenol-formaldehyde molding materials. Commonly referred to as phenolics, these molding materials are still considered the "workhorse" of the plastics industry today. Over the years, many other thermosetting compounds have been developed and are in wide use; these include urea formaldehyde compounds, melamines, alkyds, silicones, epoxies and diallyl phthalates.

When thermosetting materials are molded under heat and pressure, a basic irreversible chemical reaction takes place in the compound. This chemical reaction is known as "polymerization", defined as a change of molecular structure, converting the molding compound to a solid, infusible, insoluble state. These materials are normally supplied to the industry in granular form, having particles ranging from fine powders to coarse particles in granulations from 4 to 16 mesh. Other forms include fluffy rag-filled types, special modular impact materials, pastes and "gunks".

MOLDING OF THERMOSETS

There are four general types of molding methods used to form these materials. The first and oldest is known as compression molding. The mold consists of a cavity and a force plug. The material at room temperature, either in powder or preform state, is charged directly into the cavity of the mold, after which the force plug is lowered over the cavity and pressure is hydraulically applied to force the two halves of the mold closed, compressing the material to the proper density. Molding pressures in this process normally range from 3000 to 5000 psi on the total projected area of the mold cavities, including the flash land areas. By far the greatest volume of automatic molding of thermosets is done by the compression method, using cold powder feed. Presses of this type are supplied by such firms as F. J. Stokes, Baker Brothers, Inc., Dake Corporation, Bipel International and Hull Corporation.

The second method is also compression molding, but radio frequency preforms are used instead of the cold powder or preforms discussed thus far. Because the

material is preheated before the mold cavities are charged, less time is required to heat the material to a plastic state, the mold may be closed more rapidly and molding pressures in the range of 1,000 to 3,000 psi may be used. Cure times may be reduced as much as 30% below those required for cold powder or preform molding.

The third method is known as transfer or plunger molding. The two halves of the mold are of the matching type, similar to the design of molds used in injection molding of thermoplastic materials. In transfer or plunger molding, the mold is closed and then the preheated (225 to 275°F) material is transferred or injected from a separate pot or plunger well through a system of runners into the cavities of the closed mold. This method of molding is usually faster than compression molding because cure times, particularly for thick sections, are generally shorter. Rapid molding cycles can be obtained because additional frictional heat is developed in the already preheated material as it travels at high velocity through the runners and gates, then into the mold cavities. High velocities are the result of material being injected at pressures ranging from 6,000 to 12,000 psi.

Plunger molding is ideally suited to molding around inserts or molding intricate shapes with a combination of thick and thin sections, particularly when close dimensional tolerances are required. From an economic point of view, however, the mold cost may be higher than that of the compression type and the process involves somewhat more expensive equipment.

The fourth method is known as reciprocating screw injection molding. This is basically the same method as used for the injection molding of thermoplastics. Molds, gates, runners and sprues are of the same general design. The main difference is in the design of the screw plunger. For thermosets, screw flights and diameter are designed for an overall compression ratio of approximately 1:1.

Relatively high molding costs have, in the past, inhibited the growth of thermosetting applications. Specifically, these costs have involved intricate, high cost molds, high capital investment and labor costs in making preforms and operating radio frequency preheaters.

It is recognized in the industry that the cost of making preforms runs in the vicinity of 1¢/lb. and that an added production cost of apprximately 50¢/hr. is required for the operation of radio frequency preheaters. As a result, a new type of plunger molding press is now available to the molding industry. This is known as the reciprocating screw injector press. No preforms or separate preheating techniques are required, since cold powder is fed directly from the loading hopper into the screw barrel.

There is a substantial reduction in cycle times using a preheated charge of material. For molded parts with a thickness of 1/8" or more, the advantages of plunger molding and screw injection molding are obvious.

Considerable advantages are obtained using a preheated charge of material, particularly in the screw injection process where material is heated to a plastic state in a few seconds from frictional forces developed within the material by the rotating screw. The cycle costs on Figure 2 are based on the current press time cost of $12.00 per hour for presses in the 75-ton to 250-ton clamp capacity range.

AUTOMATIC PLUNGER MOLDING PRESSES

For many years semi-automatic molding, i.e., manually operated presses, by both compression and transfer methods, were standard in the industry. However,

because of the requirements for higher productivity at lower cost, automatic molding, with no operator, has been widely accepted in the industry. Until about two years ago, most automatic plunger molding incorporated the use of preforms, which were fed through a radio frequency preheating unit and then carried on a conveyor to the mold, where they were dropped into the open plunger well (the third method previously discussed). The mold was then closed and the hydraulic ram in the plunger well injected the material into the closed cavities. For several years, presses of this type have been on the market, notably those produced by the F. J. Stokes Company, Baker Brothers, Inc. and the Lester-Phoenix Machine Company. Very recently, Hull Corporation announced a new 75-ton, fully automatic horizontal transfer press that incorporates radio frequency preheated preforms that are dropped directly from the preheater into the horizontal plunger well of the press. Complete molding cycles as fast as 15 seconds, or four cycles a minute, can be obtained with this press. Mold charge weights up to 200 grams can readily be used (Table I).

The automatic screw injection molding press now brings overall molding cycles for thermosets down to a point where they are directly comparable to cycles for thermoplastic materials molded in standard injection presses. Both types of materials are heated to a plastic state in an injection cylinder. A thermoplastic is injected into a cold mold (seldom over 200°F) where the dwell time must be long enough for it to solidify through cooling. A thermosetting material, by contrast, is injected into a hot mold (usually between 310° and 410°F) where the dwell time must be long enough for it to cure, or polymerize, to a solid state.

Most thermoplastic materials have a low rate of heat conductivity. Therefore, when injection molding parts with wall sections of over 1/4" cycle times may be quite long. Thermosetting materials, on the other hand, are ejected from the mold hot, and the molding cycle is entirely dependent on the cure rate in the thickest section of the part. Because of the high stock temperatures obtained (250-280°F) by screw injection of thermosets, very fast cure cycles are obtained.

Thermosetting material is heated and plasticized in the barrel of the horizontal extruder and is then forced into the vertical plunger well of the press, of conventional design, which incorporates a top ram mold clamp and bottom ram for plunger injection of the material into the mold.

Presses of this type are currently being produced by the F. J. Stokes Company and the Rodgers Hydraulic Company, and are available in clamp tonnages of from 50 to 250.

Table II lists optimum conditions and data on the Stokes and Rodgers automatic screw injection presses.

The cold material is rapidly heated to a plastic state by contact with the heated barrel of the extruder and the frictional heat developed by the rotating action of the screw plunger.

The screw retracts, while revolving, to a preset position, during which time the molding material feeds into the barrel by gravity. The screw does not revolve on the forward stroke but forces the heated and plasticized material into a vertical plunger chamber where it is then forced upward by a hydraulic plunger ram into the runners and thence into the cavities of the mold.

Heater bands maintain the proper heat on the barrel while a water-cooled nozzle band prevents the material from overheating from friction, thus preventing

precuring of the material.

The heat put into the molding powder is dependent upon back pressure developed by the revolving screw and heat absorbed from the heated barrel. Should the material set up in the barrel, it can readily be removed by backing the whole extruder unit away from the transfer pot, shutting off the molding material feed valve, and then revolving the screw to discharge the hardened material.

In the vertical press of Stokes or Rodgers design, an unloading tray, which is mechanically operated, must be used. This tray is an integral part of the press and is tied in with the press opening and closing, through a system of relays and limit switches. As the molded parts are discharged onto the tray, they are swept into a discharge chute after the tray has withdrawn from between the open mold halves.

Bipel International Press, Ltd., of England, has developed a press similar to the Stokes Injectoset and the Rodgers TCIMA. The Bipel screw plunger press has a clamp capacity of 90 tons and bottom plunger ram of 22 tons. The screw is of 2" diameter and the barrel is heated with hot water to a temperature of 210°F. This press differs from other screw plunger presses in that the screw plasticizing unit can be moved forward, placing the nozzle directly over the plunger well of the open mold. A right angle elbow at the nozzle directs the preheated charge or slug directly down into the plunger well. The screw unit is then withdrawn, the mold closes, and the conventional cycle follows. The press has a shot capacity of up to 400 grams in a general purpose material.

A. Triulzi Company of Milan, Italy has recently announced its new Moldmatic "R" automatic press for thermosetting materials. The United States agents are Machine Tools International Corporation of Wayne, Michigan. The Moldmatic "R" press is essentially of the same design as the Stokes Injectoset and the Rodgers "TCIMA" press, since it incorporates a reciprocating screw plasticizing cylinder at right angle to the plunger well of the press.

The Moldmatic "R" press is available in clamping forces from 110 to 1,320 tons, with injection capacities from 285 grams to 3,650 grams. For automatic plunger molding, a weight sensing device in the unloading mechanism ensures a continuous cycle. This avoids die damage by preventing the mold from closing if the shot weight is insufficient due to a portion of the runner or a molded part retained in the mold.

The fourth method of molding thermosets may be classed as straight injection since there is no plunger well and cull of material as in the plunger molding method previously discussed. The material enters the mold through a sprue of the same design as that for thermoplastics. The thermosetting material is forced, under high pressure, through a heating cylinder and thence through a conventional nozzle to the sprue section of the mold.

Lewis Welding and Engineering Company is producing a horizontal molding press, based on the injection molding principle of press design. Thermosetting materials, in the form of cold powders, are fed into a hopper and thence into a special heating cylinder of the press. Very fast molding cycles of 12 to 15 seconds overall in thin sections can be readily obtained. The injection cylinder is heated to approximately 200°F. with either hot water or oil through a circulating pump. The cylinder nozzle is not heated but maintains a constant temperature by the heat of the materials passing through it.

A similar molding process is incorporated in the Duro-Robot press manufactured

by the Drabert Machine Works in West Germany and sold in the United States by the Polymer Machinery Corporation of Berlin, Connecticut.

New Britain Machine Company has recently announced the New Britain Ankerwerk screw injection machines for molding thermosets. These presses are available in 75 ton and 175 ton clamping capacities. It is now possible, with this type of press, to mold thermosets on cycles equal to those of thermoplastics, or even faster. This applies particularly to parts with wall sections thicker than 1/8". The unique screw design contributes to close control of stock temperatures and finite control of back pressure on the screw.

"Bakelite" phenolic molding materials BMGC-5498 Black-25 Grade 15 and BMMA-5020 Black-25 Grade 15, both general purpose formulations, were successfully evaluated at very fast cure rates.

Alfred Herbert, Ltd. of Coventry, England, is now producing the Daniels-Herbert "Transojet" screw injection machine. The screw and barrel assembly, like the Ankerwerk, is designed to provide efficient plasticizing of thermosets without overheating. This prevents precure before the material is injected into a thermoplastic type of mold. The manufacturer claims cure time reductions of up to 60%, for a given compound, over that achieved through standard compression molding.

The following materials are being successfully molded in a four-cavity terminal cover mold with sections up to 11/16" thick.

Woodflour filled phenolic, cure time 40 seconds
Cotton filled phenolic, cure time 40 seconds
Asbestos and cotton filled phenolic, cure time 25 seconds
Melamine phenolic, cure time 45 seconds
Diallyl phthalate, asbestos filled, cure time 45 seconds
Cellulose filled urea, cure time 45 seconds
Nylon filled phenolic, cure time 40 seconds

The Matsuda Seisakusho Company of Japan has recently announced[1] its new line of thermosetting injection machines which incorporate the reciprocating screw feed principle and the nozzle and sprue design already described. The Matsuda Model K-1 is basically a horizontal injection press. The mold, runner and sprue designs are similar to those used for injection molding of thermoplastics. Very fast molding cycles are reported, with minimum material loss in the runners and sprue.

Another very new press, similar to the Matsuda Model K-1, is the R. J. Thermsetter produced by the Meiki Company of Nagoya, Japan. It is available in sizes from 75 tons of clamp with a shot capacity of 300 grams, to 440 tons with a capacity of 2,000 grams.

There is one major advantage in the horizontal presses already described which should not be overlooked. In this type of press, the parting line of the mold is vertical, like injection molds for thermoplastics. This design allows molded parts to drop out of the mold after the knockout pins have pushed the parts out of the cavities. The parts are then removed from underneath the mold by an inclined chute or conveyor belt.

The Van Dorn Plastics Machinery Co. of Cleveland, Ohio is currently producing a new reciprocating screw injection machine for thermosetting materials. This

[1]Modern Plastics Magazine, December 1964, p. 135, "Thermoset Injection Machine Design" by Yugi Morita.

press is similar in overall design to their regular line of thermoplastic screw injection machines except for the screw barrel and nozzle design. This press is called the Thermoject Model 200 RS 12TS. It has a 200 ton double toggle clamp. The screw is 2" in diameter with a maximum injection pressure of 20,200 psi. The maximum shot capacity is 12 oz. or 350 grams of general purpose phenolic molding material.

The rotation of the screw is controlled by a shift lever for speeds of 30, 60 or 90 rpm. Higher speeds of 120, 150 or 180 rpm may be obtained by changing the gears in the transmission box. One of the main advantages of this reciprocating screw injection machine is the availability of screw for changing or cleaning. The whole screw injection unit is on a pivot which allows the unit to be rotated so that the screw barrel is at a 45^{o} angle to the axis of the machine. This allows quick access to the nozzle and screw.

Molding cycles and material plasticizing times for this machine are directly comparable to other similar injection machines discussed here.

The Johns Hydraulic Equipment Division of Johns Industries Pty. Ltd., Melvourne, Australia, has recently announced its new in-line reciprocating screw injection machine for thermosetting materials. This press is available in 100-ton clamp with a shot capacity of 175 grams and 150-ton clamp with a shot capacity of 350 grams. A two-cavity automotive coil cap mold has the runner and sprue of the injection type, mounted in the 75-ton press. Standard general purpose phenolic materials BMG-5000 Black and BMG-5498 Black were molded on a 45 second cycle with a 40 sec. net cure. This same part when molded by the standard compression method used in production today, requires a $2\frac{1}{2}$ minute cure and a 3 minute cycle.

One of the major advantages of this press is the accessibility of the screw ram. There are two hydraulic cylinders and rams, which are located on each side of the screw barrel, and which are connected to the gear box. Since there is no hydraulic cylinder directly behind the screw barrel and ram, the ram may be withdrawn for changing or cleaning by simply removing a back plate and inserting a "puller bolt". The hydraulic rams and yoke are then forced back under hydraulic pressure and the screw ram is withdrawn from the barrel. This is the only press we know of which has this important feature.

THERMOSETS VS. THERMOPLASTICS - MOLDING CYCLES AND COSTS

Molding cycle times can be compared for two thermoplastics, ABS and styrene, with that for general purpose phenolic in the same mold. The molded part has a ribbed section that is .231" thick. The cooling time for the thermoplastic must be long enough to prevent sink marks while the cure time for the thermosetting material must be just long enough to prevent undercure blisters. In this, and many other molded parts where there are thin and thick sections, the cooling time for thermoplastics will be longer than the curing time for thermosets, when molded by the injection method.

Cycle costs of the thermoplastics ABS and styrene, can be compared with that for general purpose phenolics in the type of injection molded part previously discussed. The press time overhead cost of $12.00 per hour was used in combination with the cost per pound and the specific gravities of each of the material types.

CONCLUSION

In their fifty-five year history, thermosets have undergone many improvements and many new products have been developed, all of which are now being used in markets formerly dominated by wood, glass, ceramics and metals. Similarly, press equipment and molding techniques have been improved to effect greater production economies and make possible design features previously thought to be impractical, if not impossible.

Now thermosets can compete directly with thermoplastics on fast production cycles. They can provide molded parts with finished properties that are equivalent, and in many cases superior, to thermoplastics, and at lower cost.

TABLE I

HULL CORPORATION

U.C.P.D. MATERIALS EVALUATION

99C Press	BMG-5000-BK-25 GR.6	BMG-5000-BK-25 GR.9	BMMA-5020 BK-25 GR.9	BMM-7002-BK-25 GR.9	BMG-2798-BK-15 GR.12	BMG-0750-NT GR. 12
Batch	3872	3877	5	535	1595	242-F
Preform Hardness	70-75	70-75	70	70	75	70
Preform Weight, gms	36	36	38	38	38	48
R.F. Preheat Time,						
sec.	8	8	7	7	6	20
Temp., °F	260	260	250	260	235	230
Pressure						
Gauge, psi	500	500	500	500	400	800
Plunger, psi	3500	3500	3500	3500	2800	5600
Fill Time, sec.	2	2	2	2	3	5
Mold Temp., °F	400	400	410	405	405	345
Mold Cycle						
Open, sec.	5	5	5	5	5	5
Close, sec.	1	1	1	1	1	1
Plunger, sec.	2	2	2	2	3	4
Net Cure, sec.	8	8	7	8	10	20
Total Cycle, sec.	16	16	15	16	19	30
Clock Cure, sec.	11	11	10	11	14	25

TABLE II

	Stokes 150 Ton	Rodgers 150 Ton	Stokes 250 Ton
Maximum mold* area, sq. in.	40	30	60
Maximum mold charge, gms.	260	454	630
Minimum cycles, sec.	40	40	50
Minimum cures, sec.	30	30	40
Normal grades of material	9	12	12
Mold. temp., top, deg. F.	360	350	350
Mold. temp., bottom, deg. F.	350	350	350
Barrel temp., deg. F.			
Back	220	215	240
Front	200	210	210
Nozzle	190-200	200	200-220
Nozzle water temp.	140-160	None	140-180
Transfer plunger dia., inch	1.5	2.25	2.0
Injection pressure, optimum, psi	8,000	10,000	10,000
Gauge pressure (line) ratio to plunger pressure (working)	Multiply by 11	Multiply by 3.3	Multiply by 9
Plunger travel time, sec.	2-6	2-6	6-10
Slug temperature, deg. F.	240-260	240-260	240-260

*Cavities plus runners

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TABLE III

NEW BRITAIN ANKERWERK

Press Specifications	75 Ton	175 Ton
Screw diameter, in.	1.18	2.16
Maximum injection pressure, psi	20,200	19,300
Maximum cavity projected area, sq.in.	35	80
Screw revolve average, rpm	76	56
Screw back pressure, optimum, psi	50-300	50-300
Shot capacity, gms.	90	320
Nozzle diameter, in.	7/32	7/32
Test Conditions		
Mold temperature, °F	390 - 410	390 - 410
Number of cavities	4 (Connector block)	2 (Blender base)
Mold area, total, sq.in.	15	48
Parts thickness (maximum), in.	1/4	3/16
Shot weight, gms.	74	285
Screw plasticize	@ 76 rpm 10 sec.	@ 52 rpm 13 sec.
Back pressure, psi	200	50
Stock temperature, °F	285	240
Injection pressure, psi	19,000	12,500
Screw travel, in.,max.	3.5	5.0
Screw barrel temp., rear, °F	160	150
Screw barrel temp., front, °F	180	210
Nozzle temp., °F	200	240
Sprue length, in.	3-9/16	3-5/8
Optimum Cycles		
Injection time, sec.	2	2
Injection dwell, sec.	3	3
Net cure, sec.	25	22
Open time, sec.	5	3
Total Cycle, sec.	35	30

Recommended Grades of Phenolic Materials

Two-Step General Purpose	-	Grade 15
One-Step General Purpose	-	Grade 18
Two-Step Heat Resistant	-	Grade 18

TABLE IV

DANIELS - HERBERT "TRANSOJET"

	Type 100-ST	Type 200-ST	Type 400-ST
Max. vol. molded/shot, cu.in.	8 (131)	15.5 (246)	27 (442)
Dia. of standard screw, in.	1-3/4 (48)	$2\frac{1}{4}$ (57)	3 (76)
Injection pressure (variable with standard screw, psi	20,700 (1450)	20,150 (1411)	20,100 (1409)
Screw speed range, rpm	40-225	40-160	25-125
Max. power available to screw, hp	10	15	40
Die clamping force, tons	100 (102)	200 (204)	400 (408)

TABLE V

MEIKI "THERMSETTER"

Clamp, tons	75
Article molded	Electric cord plug
Number of cavities	16
Shot weight	95 grams with sprue and runners
Material molded	BMM-7002-BK-25 DC, grade 12
Mold temperature, °F	365
Screw rotation, rpm	80
Screw plasticizing, sec.	13
Screw back pressure, psi	28.4
Screw barrel temperature, front, °F	198
rear, °F	162
Nozzle temperature, °F	198
Screw injection pressure, psi	17,800
Screw injection time, sec.	4
Cure time, sec.	20
Press open time, sec.	6
Total cycle, sec.	30

TABLE VI

JOHNS INDUSTRIES

Mold temperature, °F	365
Shot weight, gms.	170
Screw cylinder temperature, back, °F	185
front, °F	200
Screw back pressure, psi	300
Screw speed, rpm	50
Injection pressure, psi	12,000
Stock or slug temperature, °F	240
Screw injection time, sec.	3
Screw plasticizing time, sec.	12
Net cure, sec.	40
Overall cycle time, sec.	45

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INJECTION MOLDING ETHYLENE-VINYL ACETATE COPOLYMERS

9578-10

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INTRODUCTION

Ethylene-vinyl acetate (E-VA) resins are produced by high pressure polymerization of ethylene and vinyl acetate. Control of the ratio of the monomers present and of the variables in the polymerization process permits the production of many different polymers with commercially attractive properties for the injection molder.

E-VA copolymers meet the requirements for applications needing controlled softness and flexibility combined with excellent low temperature properties. Low density polyethylene is stiffer than E-VA copolymers. In comparison with moderately plasticized polyvinyl chloride resins, E-VA copolymers require no plasticizers or additives which can migrate from the product. There is, therefore, little tendency for the resin to harden or stiffen upon aging.

E-VA copolymers designed for injection molding are thermoplastic products which require no vulcanization, and which can be processed on equipment widely used today for polyolefin resins. The processing characteristics of these copolymers, however, differ in important aspects from those of the low density polyethylenes. This paper discusses the best techniques for molding E-VA resins.

INJECTION MOLDING MACHINERY

E-VA resins are easily processed on any type of injection molder. The reciprocating screw machine will, of course, allow the fastest cycle and lowest temperatures to be used.

In normal circumstances, machine size should not exceed the shot size by a factor greater than two. This will avert an unwarranted heat history for E-VA resins.

MOLD DESIGN

The normally used mold steels such as SAE 4140 and 4143 are suitable for use with E-VA resins. It is desirable, however, that molds be chrome plated to provide for corrosion resistance and long-term wear.

The gates and runners which may be utilized are very similar in most cases to those which are normally used for polyethylene resins. However, because the flow characteristics of E-VA resins are a little different from those of most polyolefins, very restricted gating such as is normally used with polystyrene resins should be avoided. In other words, very small pin gates or submarine gates should not be used. Other than these restrictions, any gate feasible for use with polyolefins may be used with E-VA copolymers. This would include moderate to large size pin gates, full sprues, tabs, fans, etc.

Runner systems suitable for polyethylene are suitable for E-VA resins. Parting line runners in multicavity molds should be 1/4" diameter full round, or the equivalent area in a trapezoidal runner. Hot and insulated runner systems are recommended for quality parts whenever the regrind ratio is expected to exceed 15%.

Table I indicates the shrinkage allowances for copolymers. They are normally two-thirds that of low density polyethylene. If, for instance, low density polyethylene averages a shrinkage allowance of around 22 mils per inch, the equivalent melt index E-VA copolymer should be approximately two-thirds of that value, or 14 to 15 mils per inch. These shrinkage allowances, of course, are not absolute. They will depend to a large extent on machine conditions, and perhaps to an even greater extent on the type of gating used for the part.

The draft allowance on an injection molded E-VA part should be generous. Normally a three to five degree draft will aid tremendously in ejection of the part. With a draft allowance less than two degrees, some difficulty might be expected in ejecting the part from the mold. The more flexible copolymers require the most attention to proper draft design.

As with proper injection mold design for any resin, venting should be provided at those extremities of the cavity furthest removed from the gate. The vent size should be no deeper than three to five ten-thousandths of an inch for at least the first 1/4". After that first 1/4", the vent could be deepened to two to three thousandths of an inch. These vents should be reasonably wide, but will depend on the exact type of part and its volume displacement of air.

Because of the softness and flexibility of E-VA resins, knock-out pins of generous area are required. Stripper plates can be used. Whenever feasible, air assisted ejection will aid greatly in removing parts. Again, the softer, more flexible polymers require careful attention to knock-out design to avoid punch-through or part deformation.

Perhaps the single most important design factor to be considered is mold surface. The mold surface is the principal factor controlling the gloss of the molded part. Highly polished, chromed surfaces will give high gloss (under proper molding conditions) while honed or machine finished surfaces will impair gloss but offer improved mold release characteristics and often improved part appearance (because small blemishes are masked).

Where maximum gloss is of paramount importance, an 8 to 10 microfinish or better can be used. However, the usual recommended mold surface for processing E-VA resins is a 400 to 600 grit honed surface. This is true because the inherent

softness and flexibility of E-VA resins make them somewhat difficult to eject from the mold. If a roughened surface can be utilized, air gets beneath the part much more easily to aid ejection. Field experience indicates that those customers who have honed their injection molds have significantly improved E-VA part ejection.

RESIN TYPES

Table II lists four typical E-VA resins for injection molding. Note that these resins have melt indexes of 7.5 to 22 and torsional stiffnesses from 2,500 to 14,000 lb/sq.in. These four polymers cover a stiffness range well below that of the softest and most flexible low density polyethylene.

Lower melt index E-VA copolymers than those shown also can be used in molding. However, their primary use is in short flow parts such as bumpers or feet where processability is of minimum concern.

The resins shown in Table II are competitive in properties with plasticized PVC formulations and some types of rubber. E-VA copolymer resins can be produced which are more flexible than the 2,500 lb/sq.in. torsional stiffness products shown, or which are tailored to stiffness requirements in the range of 1,000-20,000 lb/sq.in.

MOLDING CONDITIONS

Table I includes a list of maximum recommended injection molding cylinder temperatures for use with E-VA copolymer resins. Note that in some cases 450°F is recommended as a maximum temperature, and in other cases only 400°F. As a general rule, as the stiffness of these resins decreases, so does their maximum molding temperature. Most injection molders have been able to process USI's E-VA resins very easily at temperatures in the 300 to 375°F range.

The reason for limiting or placing these maximum temperatures on the use of E-VA resins is to avoid the occurrence of acific residues which could result from resin breakdown at high temperatures. These acidic residues could have a detrimental effect on the internal cylinder surface or the mold if they are not well protected.

It is recommended that E-VA resins not be allowed to remain within the cylinder of an injection molding machine for periods exceeding 30 to 45 minutes, or if the machine is to be shut down for some indefinite period of time, such as for a mold change. Simple precautions will avoid any conceivable damage to the machine. Those people who are experienced in the injection molding of flexible or rigid PVC resins should experience no problems in molding E-VA resins. E-VA resins are less sensitive to thermal degradation than many PVC formulations. The normal practice of using a rust preventative on molds is desirable.

Mold temperatures should be as low as possible, consistent with part appearance and production requirements. Of course, it is always possible to run a very cold mold at a fast cycle time, provided one keeps the mold surface temperature reasonably warm to prevent chatter, sink marks and other surface defects.

Molding temperatures are a factor in the gloss obtained on E-VA moldings. Figures 1 through 4 illustrate the effect of mold temperature on the gloss of E-VA resins processed in a highly polished mold. In these curves, a gloss value of 80 or higher may be considered good. The data show that increased mold temperatures

improve gloss more rapidly than increased cylinder temperatures, for a given resin. These graphs can serve as a guide to the molder using E-VA resins, by showing the conditions which best may be changed to improve gloss of a part.

Other processing factors, of course, can affect gloss - the melt index of the particular resin used, its vinyl acetate content or stiffness, the presence or lack of a mold release agent, as well as the cylinder and mold temperatures used. Mold release agents are effective in eliminating very tiny weld lines, chatter marks, etc., and thus improve part appearance. They are important as one factor in the total appraisal of the gloss of a part.

Experience and laboratory work have shown that cycle times for E-VA resins are about the same as those for low density polyethylene. Normally, equal or slightly longer cycle times are required. Over-all cycle times will vary depending upon the mold and cylinder temperatures used, and on the particular part molded.

These recommendations are made as a guide to the production of uniform, high quality products. Moldings have been made very successfully using 100 percent regrind, but such operation is not recommended unless production conditions are closely supervised.

RELEASE AGENTS AND COLORS

Unlike low density polethylene, E-VA resins in many applications have required the addition of mold release agents. Part ejection from a mold has proved to be the single greatest problem we have run across in injection molding these materials. The metallic stearates such as zinc stearate have proved to be highly effective in promoting mold release. The combination of mold release agents and proper design of mold knock-outs, draft and surface finish will insure production of quality parts.

E-VA resins are easily dry colored, master-batched or compounded into almost any color. Their translucent to transparent color allows an almost infinite variety of dyes and pigments to be used. Of course, adequate dispersion must be obtained in dry coloring and master-batching on ram machines. Dry colors should be very finely ground. Because E-VA resins are nearly transparent, it is possible to see below the top surface of a part, and coarsely ground pigments can be seen as apparent defects more readily than with more opaque polymers.

SUMMARY

The following practices should be observed when injection molding ethylene-vinyl acetate copolymers: 1) Design the mold to provide for the desired part finish, bearing in mind that surface finish, knock-out systems and draft will all affect part ejection. 2) For quality parts, limit the regrind ratio. 3) Allow for shrinkage approximately two-thirds that of low density polyethylene. 4) Purge the machine cylinder prior to shutdown or on standing. 5) Use an adequate dispersion disc for dry color or master-batch on ram machines. 6) Use a molding machine with a capacity no greater than twice the shot size.

The foregoing recommendations are based upon tests with USI E-VA resins. Some differences in performance may be experienced with competitive copolymers.

TABLE I

MOLDING TEMPERATURES AND SHRINKAGE ALLOWANCES FOR E-VA RESINS

Resin Type*	Torsional Stiffness, psi	Injection Molding Temperatures, ^{o}F	Shrinkage, Mils/Inch
UE 635	14,000	450 max.	14-28
UE 637	14,000	450 max.	14-28
UE 630	7,500	450 max.	10-28
UE 632	7,500	450 max.	10-28
UE 631	5,500	450 max.	10-28
UE 633	5,500	450 max.	10-26
UE 634	2,500	400 max.	10-30
UE 636	2,500	400 max.	10-30

Mold Temperature: As low as possible, consistent with part appearance and production requirements.

*ULTRATHENE(R) E-VA Copolymers

TABLE II

TYPICAL E-VA RESIN TYPES FOR INJECTION MOLDING

Property	ASTM Test Procedure	UE 635*	UE 632*	UE 633*	UE 636*
Melt Index, g/10 min.	D 1238-65T	9.0	7.5	20	22
Density, g/cu.cm.	D 1505-63T	0.928	0.932	0.941	0.948
Tensile Strength, 20 in./min.	D 638-64T (With D 412 specimen)				
Break, lb/sq.in.		1,700	1,750	1,520	1,400
Elongation, %		700	720	780	750
Torsional Stiffness, lb/sq.in.	D 1043-61T	14,000	7,000	7,000	2,500
1% Secant Modulus of Elasticity, lb/sq.in.	D 882-64T	11,000	8,000	5,280	2,500
Vicat Softening Temperature, °C.	D 1525-58T	77	66	62	47
Low-Temperature Brittleness, °C/F_{50}	D 746-64T	<-76	-76	<-76	<-76
Environmental Stress Crack, hr/F_{50}	D 1693-60T	>48	>48	>48	>48
Hardness, Durometer	D 1706-61				
Shore A		95	95	89	82
Shore D		39	36	34	23

*Code numbers for ULTRATHENE(R) E-VA copolymers, made by USI Chemicals Div. of National Distillers and Chemicals Corp.

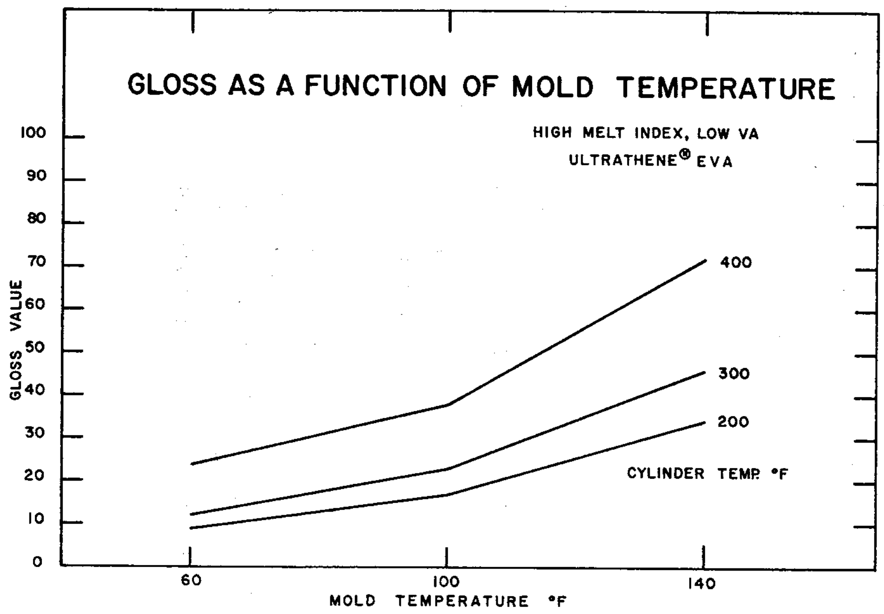

FIGURE 1

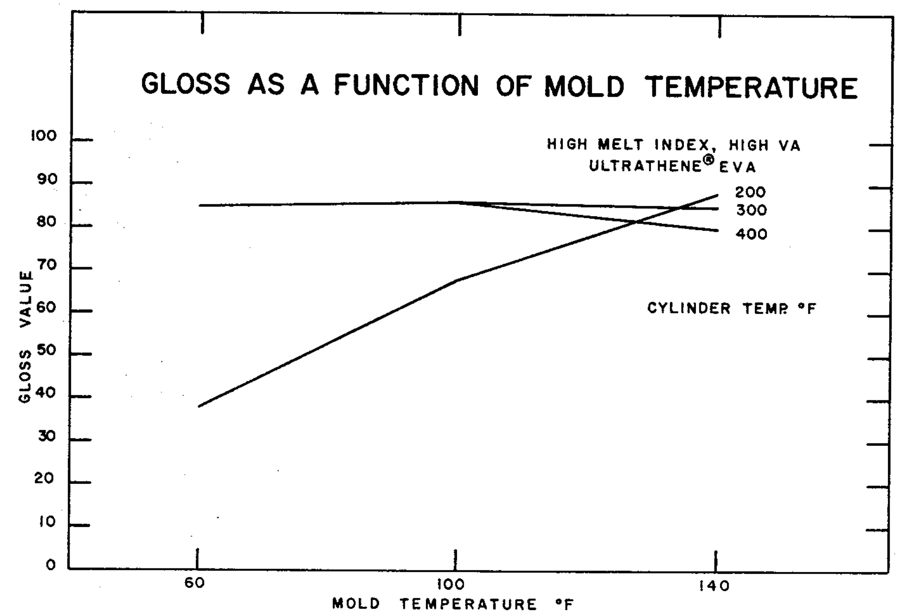

FIGURE 2

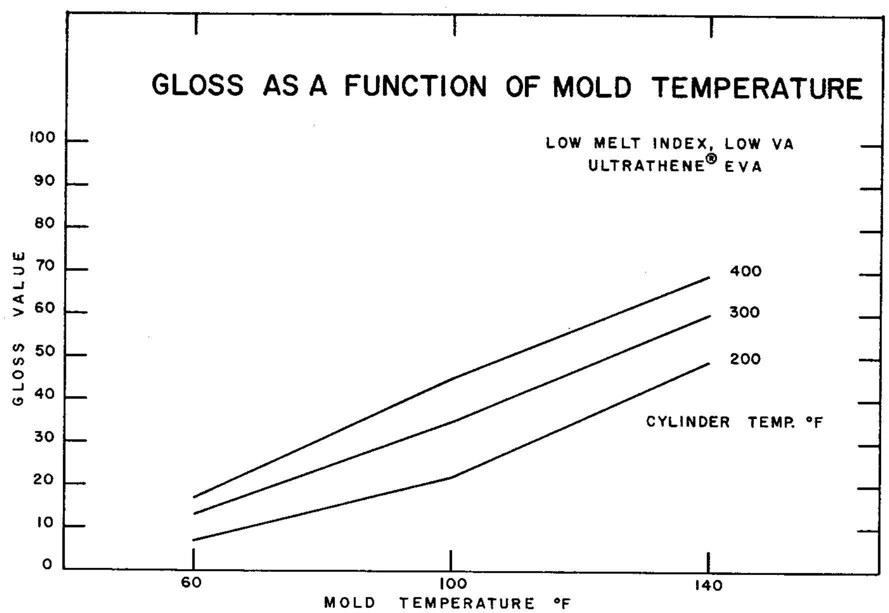

FIGURE 3

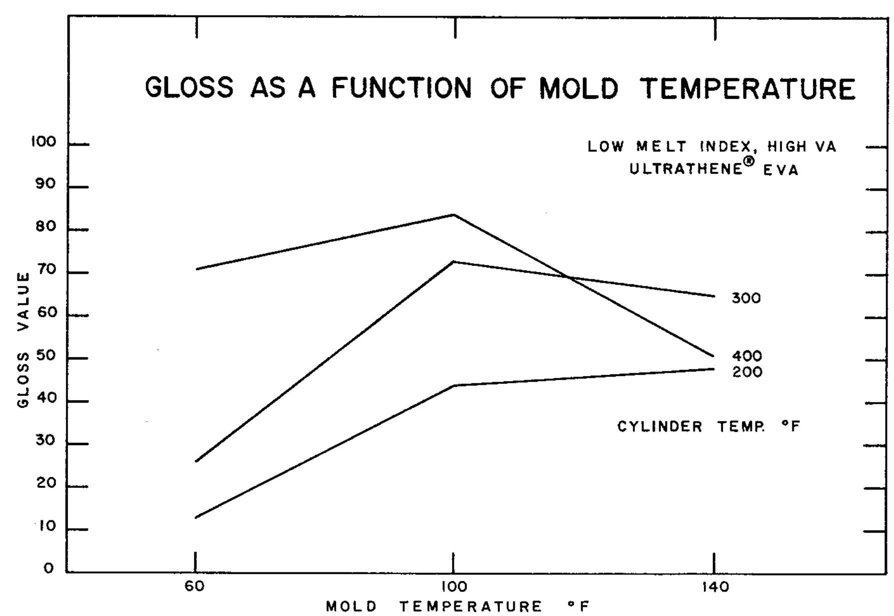

FIGURE 4

9578-11 484

PRACTICAL POLYCARBONATE MOLDING

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INTRODUCTION

Polycarbonate resins are engineering thermoplastics that are tough, transparent, heat resistant, self-extinguishing, and dimensionally stable. They are used in such applications as safety glasses and headgear, lenses, street light globes, water pump impellers, oil and water filter bowls, electrical connectors and other business machine components, computer and communications equipment, small motorized and heated appliances, air conditioners and portable tools. Modern Plastics Magazine reported that the 1965 consumption of polycarbonates in the U.S. was 15.2 MM lbs. The majority of this usage was injection molded resin. Higher volumes of polycarbonates are projected for the future, so the chances of your molding polycarbonate are increasing rapidly.

Recent introduction of easier to mold resins and refinements in equipment and molding technology have rapidly advanced the state-of-the-art of injection molding polycarbonate resin. Here the fundamentals and recent developments in molding polycarbonates will be reviewed.

FUNDAMENTALS

A. Melt Characteristics

Polycarbonate resins are amorphous and non-crystalline, which means they do not have sharp melting points. Rather, their melt viscosity decreases as temperature increases (Figure 1). Injection molding grades are not very shear sensitive. Figure 1 shows that increasing shear rates by increasing injection pressure will not substantially decrease the melt viscosity of a typical polycarbonate.

Polycarbonate resins require higher molding temperatures than many other thermoplastics, but pose no problems for molders using modern, conventional injection equipment. Cylinder temperatures of 520° to 620°F - and higher under special circumstances - are suitable for molding polycarbonate resin. At these temperatures,

polycarbonates have a broad plastic range and are thermally stable.

Currently, injection molders can choose from three grades of resin with essentially the same performance characteristics, but different melt viscosities. Figure 2 shows how the flow of the low, medium and high melt viscosity grades increases as the melt temperatures increase.

The low melt viscosity resin is best for thin sections and long flow parts such as safety glasses. Medium viscosity resin provides good flow and molding characteristics for parts with average wall thickness such as portable tool housings. High viscosity resin is best for thick parts (3/16" or more), where the effects of thermal shrinkage are pronounced.

Figure 3 can be used to estimate the flow length from the gate of low melt viscosity grade of polycarbonate resin.

B. Equipment

Although all polycarbonate resins can be successfully molded in ram machines, screw plasticizing machines are recommended. They provide better plasticization, easier fill, faster cycles and improved color control. Molding glass-reinforced resins in screw machines improves glass dispersion, enhancing part appearance and over-all mechanical properties.

Since polycarbonate resins are quite viscous at normal molding temperatures, high injection pressures are required for best results. The recommended range is 15,000 to 30,000 psi. Since mold temperatures for polycarbonate should be closely controlled within the 160° to 250° F range, an accurate mold temperature controller is required. Since polycarbonate resins must be thoroughly dried before molding, adequate resin drying equipment is essential. Either standard or dehumidifying hopper dryers or ovens are recommended.

C. Key Processing Parameters

1. Moisture Control

Dry resin is the key to successful polycarbonate molding. If the moisture content of the resin exceeds 0.03%, the resin will degrade resulting in "drooling", poor surface appearance, and brittle parts. These difficulties can be avoided by following the recommendeddrying procedures:

a. Drying Method A

Dry two to three hours in a standard or a dehumidifying hopper dryer that delivers air over the pellets at 250°F. If necessary, baffle the hopper to assure uniform air flow. Charge enough material into the hopper to maintain at least two to three hours residence time. With closed circuit dehumidifying systems the return air to the

desiccant must be kept below 160°F to keep from liberating the absorbed water. This can be done by bleeding in filtered room temperature air; using a metal return tube with enough radiation surface to dissipate the heat; or using an after-cooler.

b. Drying Method B

Dry two to four hours in a standard or dehumidifying oven in open trays (one inch maximum depth of pellets).

Note: Moisture saturated pellets or regrind (depending on particle size) will require up to four hours at 250°F. In order to keep the resin dry, keep the hopper covered at all times and do not charge with more pellets than required for $1\frac{1}{2}$ hours of molding. Once the pellet temperature drops below 230°F, the pellets begin to pick up moisture. If the resin is in the hopper longer than $1\frac{1}{2}$ hours, it may pick up enough moisture to cause problems. This is especially true on humid days.

Figure 4 shows how the drying of wet resin improves notched Izod impact strength.

Figure 5 shows how proper drying of the resin enhances the appearance of injection molded polycarbonate parts.

2. Contamination Control

Since contamination with small amounts of ABS, SAN and nylon can severely degrade polycarbonate resins, machines should be thoroughly purged of other materials prior to running polycarbonate. The best materials for purging are acrylic, crystal polystyrene and high density polyethylene.

3. Melt Temperature Control

Although thermally stabilized polycarbonate resins have good melt stability at normal processing temperatures, accurate temperature control is required when molding some opaque white and pastel, and some transparent and translucent colors. Since melt temperature is a function of cylinder temperatures and residence time in the cylinder, the proper size equipment should be used. Best temperature control can be achieved by running at 50 to 75% of capacity. "Hot spots" and/or areas where material may hang up should be avoided.

MACHINE SET-UP AND MOLD DESIGN

A. Screws

Although polycarbonate resins have been successfully molded on all kinds of screw injection machines, best results are obtained with

the following screw design. Screws should be made of stainless steel or chrome plated. Although screws as short as 15 diameters can be used, screw lengths of 20 diameters or more are recommended. A full flight, constant pitch screw with a short feed and metering section is preferred. The channel depth in the metering section should be a minimum of 0.10". The use of restricted or rapid transition areas, as are used for nylon, should be avoided. Compression ratios of 2:1 to 3:1 are recommended. Screws with higher compression ratios tend to reduce output and cause high frictional heating, resulting in streaks and degradation. Since polycarbonate resins are viscous, rotary or slide valves are not recommended because they restrict flow and cause hang-up. If they are used, they should be designed for free bleeding to reduce contamination. Normally, it is not necessary to cool or heat screws when molding polycarbonate resins.

B. Nozzle

The nozzle should be designed to minimize resistance to plastics flow and transmit maximum pressure to the mold cavity. Constant bore diameter nozzles are recommended (3/16" to 1/4" for up to 4 oz. machines, 1/4" to 3/8" for up to 20 oz., 3/8" to 1/2" up to 60 oz., and 3/8" to 1/2" for 60 oz. and over). Nozzles should have a sharp orifice radius and a short land. They should be equipped with heater bands with separate controls. The diameter of nozzle opening should be about 20 to 25 mils less than the tip of the sprue bushing. If the opening is too small the resulting frictional heat build-up could cause silver streaking.

For best results, nozzle temperature should be equal to or slightly lower than the front cylinder temperature. Excessively high nozzle temperatures may cause drooling. Lowering the nozzle temperature 10 to 25°F should halt this condition. Cut-off nozzles are not normally recommended when molding unreinforced resins but may be needed to prevent drooling with glass reinforced resins.

C. Sprue Bushing and Sprues

Standard sprue bushing and sprue designs are usually adequate for polycarbonate, except that larger diameters are required. The nozzle end of the sprue should be at least 3/16" in diameter for up to 16 oz. machines; 3/16" to 1/4" for up to 60 oz. machines; at least 1/4" for machines larger than 60 oz. The diameter at the runner should equal the runner minimum. The sprue should have a good taper, 2 to 6°, and be well polished. Cold-slug-wells equal to the diameter of the sprue and ending 3/8" to 3/4" below the runner are required. Any of the conventional sprue puller designs such as "Z", reverse-taper, "groove", and sucker-pins are acceptable. If a sucker-pin is used, care should be taken to provide a cold-slug-well at the base of the sprue to avoid restricting the resin flow through the primary runner.

Sprues for glass-reinforced resins should be highly polished and somewhat larger than for unreinforced resins. A taper of $2\frac{1}{2}$° per side minimum is recommended.

D. Runners

Balanced layouts and full-round or trapezoidal runners are recommended. Cold-slug-wells should be provided at the end of each runner where the material flow changes direction. Table I summarizes the recommended diameters for full-round runners of various flow lengths.

Glass reinforced polycarbonate runners should be full-round, with a ratio of volume-to surface area somewhat higher than those for unreinforced polycarbonates.

E. Gates

The design, flow, appearance and finishing requirements of the part determine the best gating.

The following kinds of gates have been successfully used with polycarbonates: edge, jump, tab, fan, flash, sprue, diaphragm and tunnel or submarine.

Experience will usually indicate the best location, but, where possible, gates should be located at the thickest section of the part and should open against a wall or boss to reduce splay. Unless absolutely necessary, do not gate at a critically stressed region of the molding.

Gate lands should be kept as short as possible to prevent premature freezing off. In some cases, reducing land length to a minimum of 20-40 mils improved flow as much as doubling the gate size. Gates should be as close to square as possible. They should be at least 1/2 - 2/3 the thickness of the thickest section of the part. Usually, the smallest gate that will fill is used. However, if gates are too small, the results will be difficult filling, splay from frictional heat and sinks caused by fast freezing off. Gates that are too large cause higher removal cost, longer cycles, imperfect surfaces, and high packing stresses. Sink marks also may occur near too large a gate. On heavy section parts the gate should be large enough to fill with a slow ram to eliminate internal voids and sinks.

Pinpointing gating is not generally recommended but can be used for small parts with uniformly thin walls.

The optimum gate size for molding glass-reinforced resins depends on many variables. It is best to start out by following the recommendations given for unreinforced resins and then to modify them as required.

Edge gating is generally used on simple housings where appearance and/or fill are not too critical and minimum degating effort is required.

Jump gating is frequently used to eliminate splay and surface blemishes. Figure 6 shows a jump-gated shaver housing base made in a two-plate mold and gated on the mold parting line. The depth of a jump gate can range up to the wall thickness; the

length and width should be equal or greater than the part thickness. Milling is required to assure burr-free gate removal.

Tab gating is used on appearance parts to reduce "jetting" and splay. Figure 7 shows a typical tab-gate. Thickness of the tab should range from one-half to full wall thickness; the width of the tab should not exceed one-fifth of the part length for small parts, or 1/2" for large parts.

Fan and flash gates are generally used on wide, flat, or slightly curved hard-to-fill parts. One major drawback is that parts must be degated with a band saw.

Figure 8 shows a typical sprue gate used on safety helmets. Use of a 1/8" radius at the bottom of the sprue assures maximum impact resistance.

Diaphragm gates work well on round cylindrical parts because they provide uniform fill, make possible closer tolerances, and eliminate weld lines. Figure 9 shows the proper relationship between wall and diaphragm thickness. Milling or fly cutters must be used to de-gate diaphragm gated parts.

Tunnel or submarine gating has been successful in eliminating surface appearance problems (particularly splay) and in simplifying gate removal in a number of products such as portable tool housings, business machines tape cases, safety glass lenses, and transparent covers. Parts can be tunnel gated on vertical side walls or through a knockout pin such as shown in Figure 10. Gate diameters ranging from 0.050" to 0.125" have been used successfully.

F. <u>Vents</u>

Molds for polycarbonates should be properly vented to enhance filling and minimize burn marks caused by trapped gases. Since polycarbonates are inherently viscous, vents 1/8" wide and up to 0.003" thick can be used without causing flash. Because rapid filling is highly desirable in glass-reinforced resins, multiple vents up to 0.004" are recommended.

G. <u>Mold Temperature Control</u>

Although polycarbonate resins can be used in unheated molds, best results are usually obtained when mold surface temperature is between 175° to 230°F. The higher melt temperatures and pressures required to fill a cold mold may result in higher frozen-in stresses, which could result in crazing if the parts become exposed to certain chemicals. Cold molds may also cause poor surface appearance. Hot molds turn out parts with the best appearance, and lower residual stress. However, if the molds are too hot, greater shrinkage, longer cycles and warped pieces may result.

Almost all of the polycarbonate parts are run at 180° to 200°F mold temperatures. Thick-walled parts, however, such as filter bowls, are run at about 160°F mold temperature; conversely, thin-walled lenses are run at about 220°F. When molding glass-reinforced

resins, the mold temperatures should range from 150 to 250°F. The higher mold temperatures (180° - 250°F) result in better knitting around inserts or core pins, and improved surface appearance.

Special "cold fingers" should be incorporated in long core pins that dissipate the heat slower than other parts of the mold. Parts with large areas, long draws, thin sections, complex shapes and multiple cavity molds with long runners usually require higher molding temperatures - 230° to 250°F, and should be well cored to provide accurate temperature control.

Since the actual measured temperature of the mold frequently varies considerably from the temperature measured in the circulating heat-transfer media, care should be taken to control the actual mold surface temperature, not the media temperature.

H. Mold Shrinkage and Draft

Since polycarbonate resins are amorphous (non-crystalline) they exhibit very low and predictable mold shrinkage as compared to many other thermoplastics. Table II gives typical mold shrinkage values and draft requirements for both unreinforced and glass-reinforced polycarbonate resins. Packing in the mold from high pressure or stock temperature can cause some minor shrinkage variations in both unreinforced and glass-reinforced polycarbonate. Undercuts should be avoided since the rigidity and toughness of polycarbonate resins will result in ejection problems.

I. Hot Melt Transfer Molding

Since polycarbonate resins are melt stable over a broad temperature range, they can be readily molded by the "hot tip" or "hot manifold" processes. Both processes involve keeping the material molten from the tip of the machine nozzle to within 1 to 2" of the mold cavity. Table III compares hot melt transfer molding with conventional two or three-plate injection molding.

Molders should remember that melt viscosity increases rapidly as the temperature decreases. Consequently, hot tip or manifold molds must be designed so melt temperature can be accurately controlled at 520° to 620°F. Best results to date have been obtained in molds where the melt passed through an internally heated manifold, i.e., one with a cartridge torpedo or heater in the center of the melt stream, as shown in Figure 11. Externally heated manifolds dissipate too much heat into the mold base and give poor temperature control. Variac regulators are recommended. They produce a more constant, even heat than the "on-off" controllers. When using heated manifolds, each tip should have a separate temperature control device.

During initial start-up, gradually raise and lower the heat until the temperature response can be gauged. Attempts to rapidly raise the temperature may cause overheating, resulting in parts with streaks, black specks. Since line voltage variation can cause significant melt temperature differences, it is important to locate thermocouples strategically in the system to measure operating temperatures. These readings should be carefully recorded and used

as guidelines in subsequent start-ups.

Manifolds and melt flow channels should be designed to minimize restrictions and hang-up. The hole diameter at the tip of the hot melt bushing should be between .090 to .125".

Table IV gives examples of polycarbonate parts being successfully molded by hot tip or manifold techniques.

Polycarbonates are also being successfully molded in "insulated runner molds". One-inch diameter runners are satisfactory on those parts where wall thickness permits total cycles of 45 seconds or less. By using cartridge heaters to maintain fluid melt, the cycles can be increased to approximately 60 to 75 seconds.

OPERATING PROCEDURES

A. Cycles

When molding polycarbonate, the best cycle calls for a quick fill, a hold time long enough for the gates to freeze, and a brief cure period. The fastest possible injection stroke is best for most parts, but for very thick sections, a somewhat slower stroke is better. The most important factor determining the cycle is part thickness.

B. Typical Operating Conditions

1. Unreinforced Resins

Table V gives typical operating conditions for unreinforced polycarbonate resins.

Higher temperatures are recommended in the rear heating zone unless molding is done at a very low percentage of the machine capacity. In this case, the rear is run cooler to prevent excessive heat during a long residence time in the cylinder, e.g., rear - 500°F, middle - 540°F, front - 540°F, nozzle - 540 to 580°F.

The "cushion" of material remaining at the end of each injection stroke should be no more than 1/8". Although larger cushions help to even out machine fluctuations and reduce the chance of short shots, a large mass of partially melted resin significantly reduces the available "hydraulic" pressure required to fill the cavity. Raising the melt temperature to compensate for this pressure drop may cause "brown streaking".

To avoid ripples (or fingerprinting) when molding thin-walled parts, use maximum, injection speeds. If jetting occurs, the gates may need to be enlarged or modified. Slower injection speeds will minimize molded-in strain on sprue-gated parts such as filter bowls, which are subjected to cyclical pressures when in use. "Boosters" are used to speed up the injection stroke. They should be cut

out during the final 1/2 to 1" of travel to avoid packing.

High screw rpm and back pressure can generate enough frictional heat to cause brown streaking and general degradation. Screw rpm should be reduced to the minimum required to complete the screw return before the press opens. Screw back pressure should be minimized at about 50 psi.

2. Glass Reinforced Resins

Table VI summarizes typical temperature profiles for 20 and 40% glass-reinforced resins.

Variations in flow lengths, wall thicknesses, and shot sizes will require changes in the suggested profiles. Raising temperatures will usually improve surfaces, dispersion, and filling of thin sections.

Rear zone temperatures may vary as much as $\pm 50^{\circ}F$ depending on shot size per machine capacity relationships and cycle times. Higher rear zone temperatures are particularly important on ram equipment to insure early melting of the pellets and thereby prevent a pressure drop caused by compressing cold pellets on the rear of the spreader.

Nozzle temperatures are usually 10 to $15^{\circ}F$ lower than front zone levels.

Maintenance of fast and constant injection or ram speeds is important. However, speed may have to be reduced when jetting, burning or difficulties in filling thick sections occur. A constant 1/8" cushion is suggested.

Injection pressure for glass-reinforced polycarbonate should be between 15 to 20,000 psi. Clamp pressure of 3 to 5 tons per square inch of projected area is recommended for typical parts, higher for thin parts.

In screw press operation, screw turning should be stopped just before the mold is opened. Back pressure on screw should be 50 to 400 psi. This will minimize mechanical working of the resin and avoid excessive and uneven frictional heat build-up.

Even under optimum operating conditions, some darkening of the glass-reinforced resin may occur. This is caused by the action of the sizing, or wetting agent, on the glass, and the mechanical working of the resin during molding. While even very dark parts may be of high quality, severe color change may indicate resin degradation, and moldings should be checked accordingly.

C. Shut Down

If another material is to be run next in the machine, it should be purged with acrylic, crystal polystyrene or high density polyethylene. Polycarbonate resins can be left in the cylinder overnight or over a weekend only under the following conditions:

*Reduce cylinder temperatures to 300-350°F;

*Leave the heaters on;

*Make certain temperatures do not drop below 300°F. (Below this limit, polycarbonate adheres to the cylinder walls, and it may pull bits of metal oxides and degraded resin off the cylinder walls while cooling. This contamination would appear in the next molding as black specks);

*Purging during heat-up or cool-down prevents the resin from laying motionless against the hot cylinder walls thereby avoiding local overheating and degradation.

SUMMARY

All polycarbonate resins are being successfully injection molded in a wide range of applications on both ram and screw presses. The "key" to practical polycarbonate molding lies in understanding the melt characteristics of the resin, in designing the mold and setting up the machine to account for these characteristics, and in following the recommended operating procedures.

TABLE I

RUNNER DIAMETERS AS A FUNCTION OF RUNNGER LENGTH

	Runner Length	Full-Round Runner Dia.
Primary	10 in. long or above	.375
	3 in. to 10 in.	.312
	3 in. or under	.250
Secondary	Any	.250 min.

TABLE II

POLYCARBONATE MOLD SHRINKAGE RANGE AND DRAFT REQUIREMENTS

	Mold Shrinkage	Draft
Unreinforced	.005 to .007 in./in.	1/2°/ side min.
20% glass reinforced	.002 to .003 in./in.	1/2°/ side min.
40% glass reinforced	.001 to .002 in./in.	1/2°/ side min.

TABLE III

HOT MELT TRANSFER MOLDS AS COMPARED TO CONVENTIONAL TWO OR THREE-PLATE MOLDS

Advantages	Disadvantages
Minimum scrap, trimming	15-25% higher initial tooling and set-up costs
Better appearance, quality	More complex set-up
Thin sections, easier to fill	More precise start-up temperature control required
More cavities per mold	
Full automation	
Shorter cycles, particularly on thin parts	

TABLE IV

POLYCARBONATE PARTS SUCCESSFULLY MOLDED BY HOT MANIFOLD/HOT TIP TECHNIQUES

Eight-inch diameter light diffuser	Single cavity - hot tip - center gated
Flashlight lens ring	Four cavities - hot runner manifold with tunnel gates
Flashlight base plug	Four cavities - center gated - hot manifold and tips
Appliance housing	Single cavity - hot manifold - 6 tips
Three-piece magnetic tape cartridge	
Outer frame	Two cavity mold - hot manifold and tips into diaphragm gates
Inner frame	Two cavity - hot manifold and hot tips feeding short sprue and runner
"Wrap around" tape reel protector	Single cavity - hot manifold - 4 hot tips

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TABLE V

TYPICAL OPERATING CONDITIONS FOR UNREINFORCED POLYCARBONATE RESINS

Mold temperatures	Front	180° to 200°F
	Rear	180° to 200°F
Cylinder temperatures	Front	550° to 575°F
	Middle	560° to 585°F
	Rear	570° to 600°F
Nozzle temperature	Same as front cylinder temperature or slightly lower	
Pressure	3/4 to full	

TABLE VI

TYPICAL TEMPERATURE PROFILES FOR GLASS REINFORCED POLYCARBONATE RESINS

Type of Press	Rear, °F	Middle, °F	Front, °F	Nozzle, °F
Ram	625	575	575	565
Screw	525	575	575	565

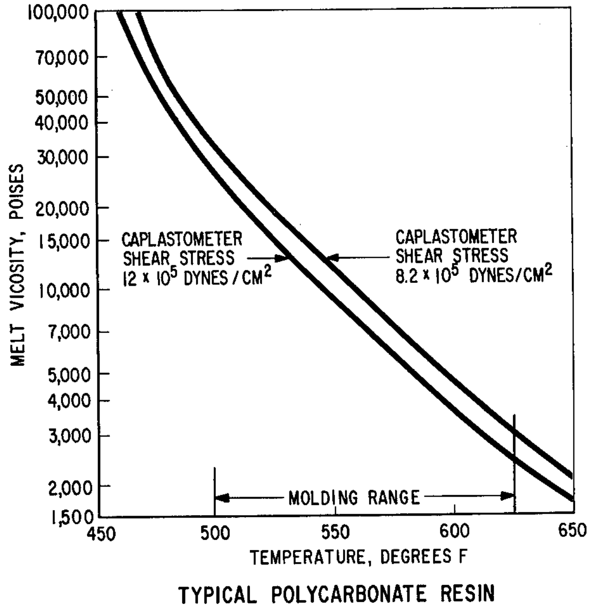

FIGURE 1: Melt Viscosity vs Melt Temperature at Two Shear Stress Levels

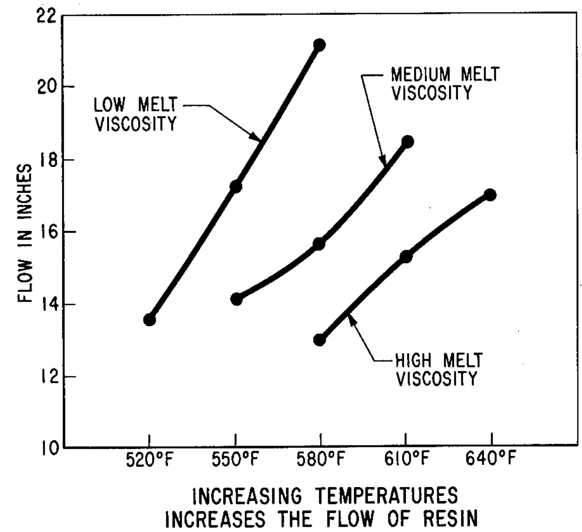

FIGURE 2: Flow Characteristics of Injection Molding Grades

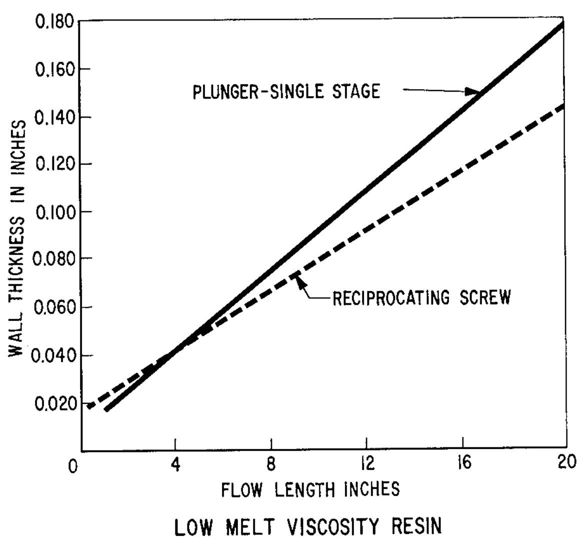

FIGURE 3: Distance of Material Flow From Gate vs Wall Thickness

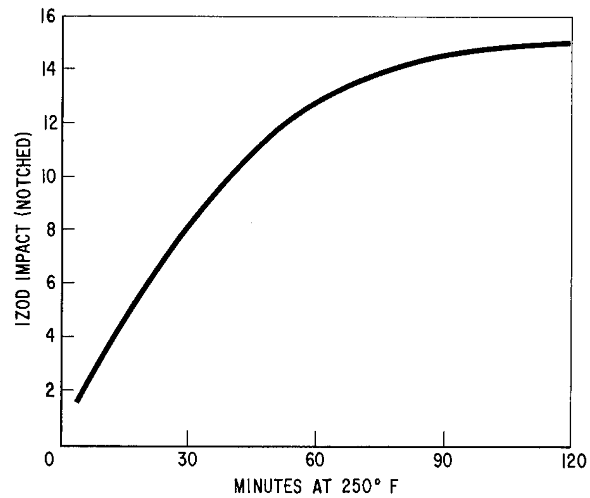

FIGURE 4: Effect of Drying Time on Impact Strength

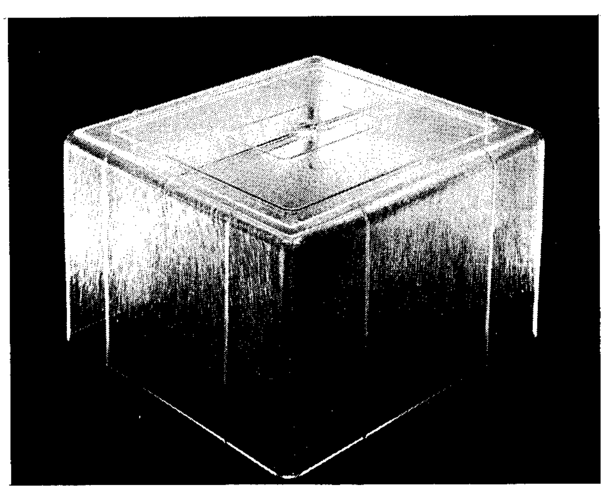

FIGURE 5A: Effect of Proper Drying on Appearance of Molded Parts – Wet Resin

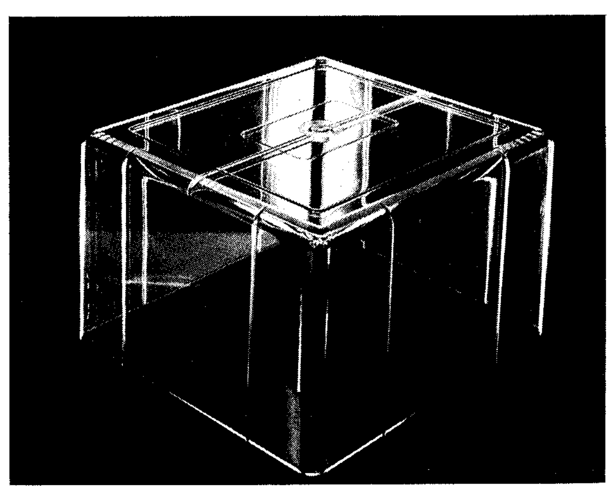

FIGURE 5B: Effect of Proper Drying on Appearance of Molded Parts – Dry Resin

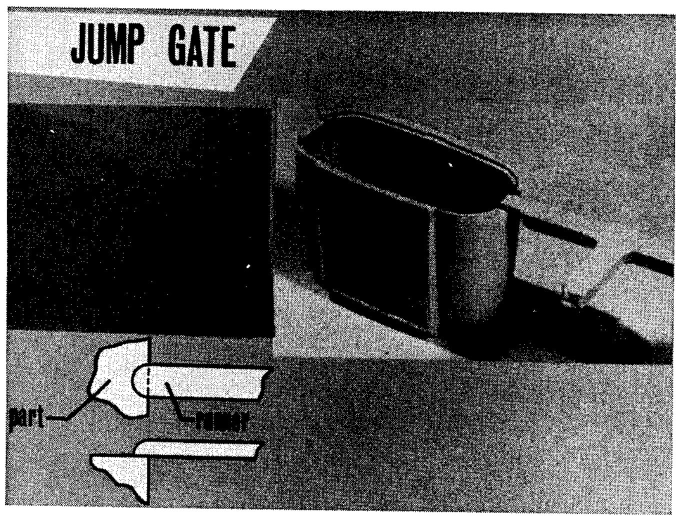

FIGURE 6: Jump-Gated Shaver Housing Base

TAB GATE

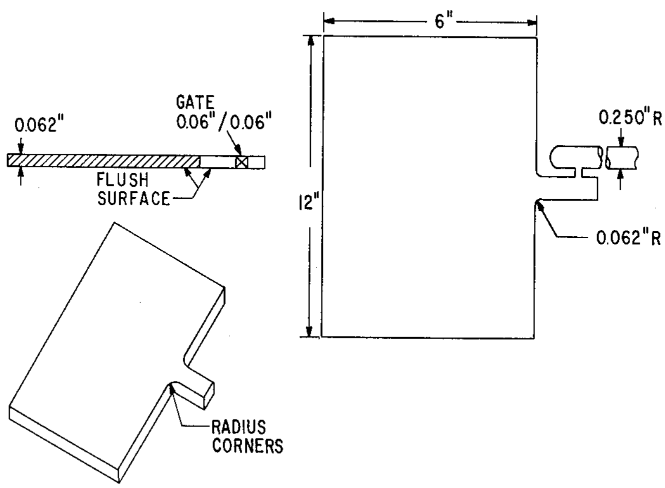

FIGURE 7: Typical Tab-Gate Design

SPRUE GATE

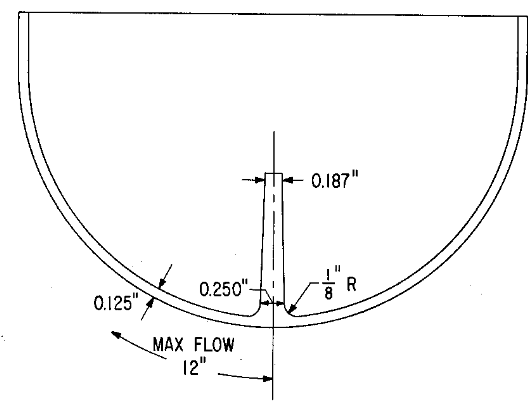

FIGURE 8: Typical Sprue-Gate Design for Safety Helmets

DIAPHRAGM GATE

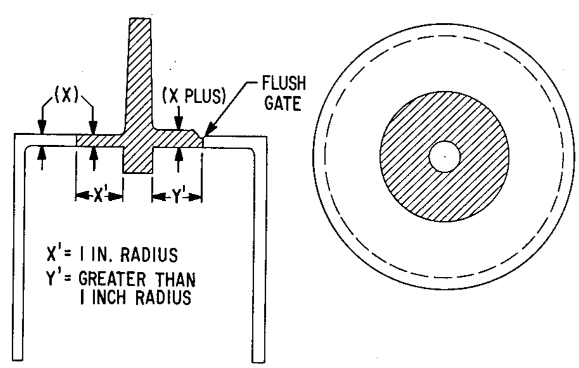

FIGURE 9: Recommended Thickness for Diaphragm Gates

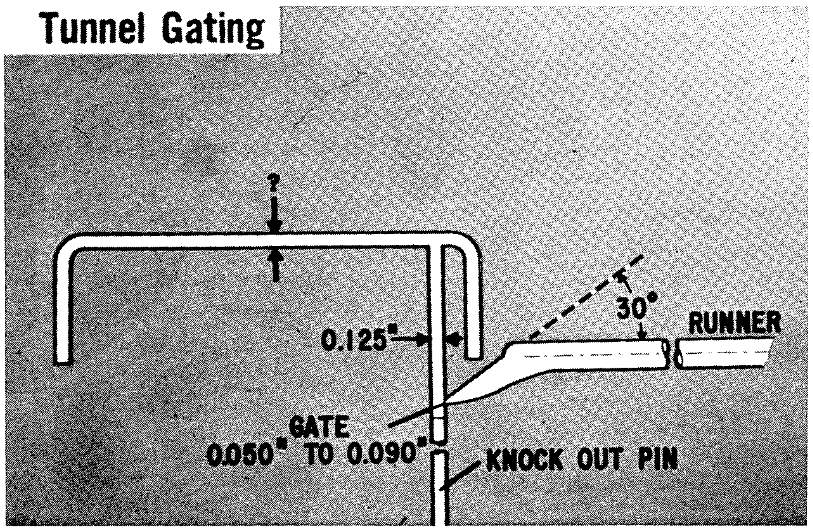

FIGURE 10: Typical Design for Tunnel-Gate Into Knock-out Pin

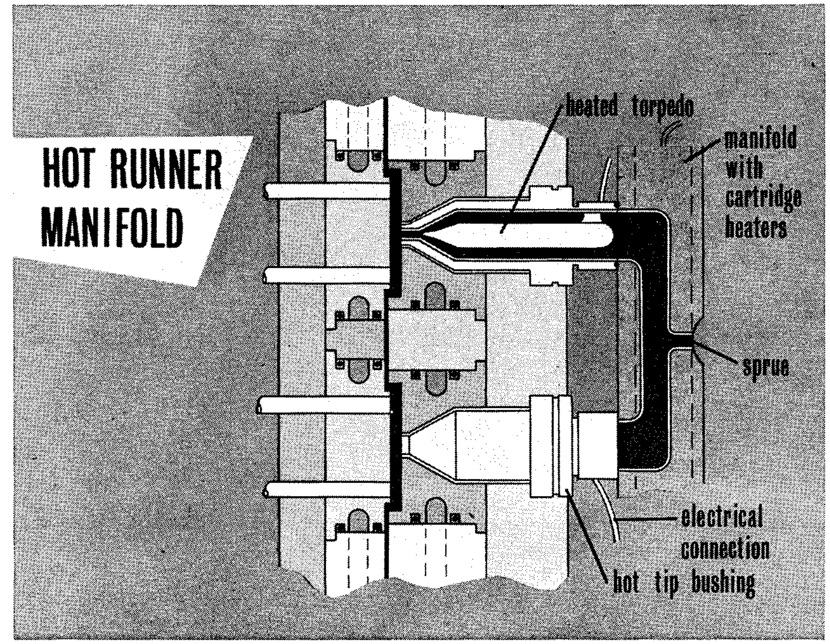

FIGURE 11: Typical Hot Runner Manifold and Hot Tip Bushing Design

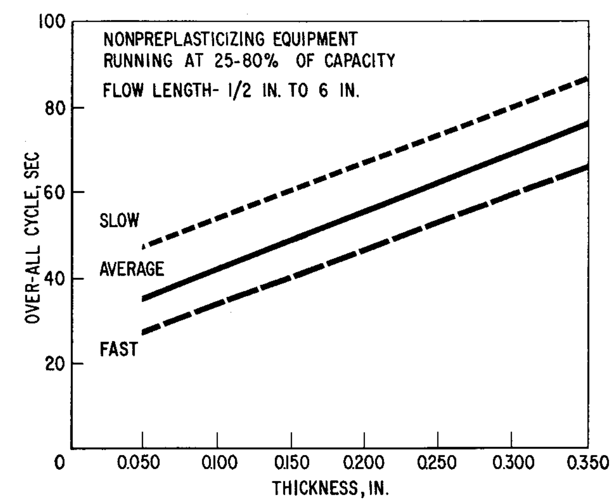

FIGURE 12: Typical Over-all Molding Cycles as a Function of Part Thickness

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EXTRUSION OF URETHANE ELASTOMER RESINS

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TEXIN(R) resins are urethane elastomer resins which are supplied in pellet form suitable for processing on conventional thermoplastic equipment such as injection molding machines and extruders. The purpose of this paper is to describe applicable techniques for extruding the three hardness grades of the material. Particular emphasis is placed on pre-drying of the resin, extruder screw design, preferred barrel temperature profiles, and take-off methods for sheet, tube and cable jacketing.

The recommended procedure for pre-drying TEXIN resins is to heat the material for one to three hours at a temperature of 200 to 230°F. In an extrusion operation, the best way to do this is to have a hopper sized so that the material may have about a two hour residence time in the hopper. Use of a dehumidifying hopper dryer to preheat the material is recommended. Feasible alternatives to this procedure are discussed.

The most satisfactory screw to use with TEXIN resins is the so-called "general purpose screw" where about 25% of the screw is feed depth, about 50% of the screw is a gradual transition from feed to meter depth, and 25% of the screw is meter section. The compression ratio should be about 2.5 to 1 or 3 to 1. Recommended meter depths for each size extruder screw and theoretical output rates are given. Problems associated with other common screw designs are discussed. The point is made that in no case should the screw have a rapid transition from feed to meter depth as this will overheat and degrade the resin.

Preferred barrel temperature profiles are given which yield a melt temperature of 390 to 410°F. for TEXIN 480-A and a melt temperature of 430 to 440°F. for TEXIN 355-D. Under these conditions, the extrudate for TEXIN 480-A should be translucent to transparent, while the TEXIN 355-D extrudate will be a light, but opaque tan. TEXIN 480-A is the only grade of the material which can be extruded in transparent form.

Take-off methods for TEXIN 480-A must be predicated on the fact that the extrudate is a somewhat sticky material which will block unless separated from itself or adequately quenched in water baths. Thus, 480-A sheet is normally extruded with the aid of a release paper interleaf. Other techniques important in producing TEXIN 480-A sheet are discussed. Experimental samples of TEXIN 355-D sheet will be displayed along with commercially available forms of many different extrusions, such as rod, plate, cable jacketing and shapes.

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NEW POLYSTYRENE APPLICATIONS

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INTRODUCTION

During the past year, those of us in the plastics industry have witnessed, or perhaps been a part of, the development and market introduction of literally thousands of new and exciting plastics applications. We have also seen several application concepts finalized in terms of material, processing technique, and design during this period - a few of which have been in development for some years.

Speaking for the styrene portion of the plastics industry, this period has been particularly encouraging for us with respect to technological advances and the market potentials involved in new applications in areas such as packaging, major and small appliances, radio and TV cabinets, and furniture components. Although time does not permit our covering even half of the noteworthy advances in these areas, I would like to summarize for you, three of the potentially big volume styrene applications which, in our opinion, are well on their way to becoming long lasting successes in our industry.

INJECTION BLOW MOLDED BOTTLES

The first of these is injection blow molded bottles which, until quite recently, many observers had written off as being a small volume specialty market. Basically, the objections to any type of blow molded styrene container centered around the material's relatively high brittleness and its poor moisture vapor and oxygen barrier properties as compared to the well established polyethylene materials.

Two things, however, have happened during the past year or so. One is the development of processing technology which has greatly reduced the brittleness problem. The other is the realization that many products do not require the ultimate in oxygen or moisture barrier protection from the package. With these main objections now in their proper perspective, many packaging engineers are now seriously considering the use of injection blow molded styrene vials and jars for ethical and proprietary drugs, talcum powders, pet foods, cosmetics, and a variety of foods. Many of you are undoubtedly familiar with the successful Chesebrough-Ponds petroleum jelly jar. Although the reasons for considering this type of container vary from one potential user to another, the main selling points versus glass containers usually include: Much lighter weight with attendant lower shipping costs, and improved shatter resistance with far less dangerous fragments resulting when containers do break. The main selling points versus polyethylene usually involve: High clarity and vastly improved rigidity, decorability and gloss.

The injection blow molding process, in its general description, is ingeniously simple. Although the details of most machinery and techniques are proprietary and very much under wraps, the process is generally as follows.

High heat crystal styrene is fed into a standard screw injection molding machine where it is heated to a stock temperature of about 425°F. It is then shot into a highly specialized mold equipped with a cartridge heated manifold or runner system. The cavity (which can range in number up to eight or twelve) is usually constructed such that the resulting part, or parison as it is called, is shaped much like a heavy walled pharmaceutical vial. Depending upon the style of the final part, the parison may be molded with threads to accept screw-on closures, or a beaded rim for use with snap on polyethylene lids.

A unique feature of many of these parisons is that the wall thickness is varied to assure proper material distribution during the blow operation. The parison could also be designed with changes in wall thickness circumferentially, which would then permit the blowing of irregular or non-cylindrical parts with uniform wall thicknesses. For this type of work, injection blow molding should prove far more versatile than extrusion blow molding since parison control in the latter process is quite complicated.

Once the parison cavity is filled and the pinpoint gate at the base is frozen off, the mold cavity is split open in clam-shell fashion and the parison is quickly transferred to the adjacent bottle cavity without being stripped from the core. After the bottle cavity is closed and locked, the core is extended slightly and hot air is blown into the parison. This releases the hot, still viscous styrene from the pin and forces it outward and up against the mold walls. In so doing, the material is given a true biaxial orientation which greatly improves the toughness of the resulting bottle.

After a few seconds of contact against the rather cool walls, the bottle mold is cracked open, the piece is removed from the neck section of the force, and is then ready for decorating or pack-out.

Since the necks of these containers are essentially injection molded surfaces, trimming and reaming are not necessary. As well as helping to bring the cost picture closer to the faster extrusion blow molding operations, the injection molded neck offers the added advantages of closer thread and neck diameter tolerances. When these bottles are run on high speed filling lines, these closer tolerances could be converted to very real cost savings.

As mentioned earlier, the styrenes used for injection blow molded bottles are usually first quality high heat crystal styrenes. These have been chosen over the softer flowing general purpose grades primarily because of their better hot strength and faster set-up characteristics. Limited feed back indicates that they produce a somewhat stronger bottle as well due to their ability to develop higher stress levels. For applications where long term ultraviolet light exposure is anticipated, specialty light stabilized resins are available which meet FDA criteria for safe use in food contact.

Although the commercial acceptance of this application is still in its infancy, the indications shown to date strongly suggest that polystyrene, with its good rigidity, crystal clarity, and low material cost, will assume a very solid position in the bottle industry within the next few years. During the calendar year 1966 most figures indicate that approximately 6-8 million pounds were used by the injection blow molded bottle producers. Future growth will assuredly continue at a steady rate.

FURNITURE COMPONENTS

A second new growth area for polystyrenes which has come upon us rather suddenly is in wood substitute applications such as injection molded furniture components, TV cabinets, appliances and decorator type items such as plaques, frames and clock parts.

The sudden demand for polystyrene in these areas has a brief but interesting history. For several years the furniture and home furnishing manufacturers have faced serious shortages of clear grained hardwoods, particularly mahogany, walnut, cherry and maple. With a growing demand, brought on by our population explosion, it is simply not possible to grow trees as fast as U.S. industry wants to produce furniture. Up until the past few years, this condition was a relatively minor problem since the furniture styles were largely centered around the Early American or Danish Modern designs. With reasonable care, attractive, low-cost furniture was produced from the more available woods such as maple, pine, birch and plywood veneers of the more costly woods. Usually these designs avoided the use of complicated carvings or other fancy work other than an occasional piece of millwork for accent.

In the past few years, however, the stylists were finally able to convince the U.S. consumer that a change in decor was in order. As replacements for the Early American and Danish styles, versions of English, French, Spanish and Italian Provincial or Renaissance were offered. Initially these groupings were confined to the high priced end of the market because of high labor costs required to machine, carve, assemble and finish these elaborate pieces. They also required the use of the scarce and costly fruit woods, walnut, or other hardwoods needed for high production machining or hand carving. Naturally, with the high priced end of the market setting the trend, demands for similar styling quickly arose from the consumer seeking low priced furniture. With shortages in wood, labor and machining capacity already facing this industry, a wood substitute was needed which would allow manufacturers to side step these and produce intricate wood-like panels, appliques and moldings on a fully automated line.

At the same time, the TV manufacturers were facing a similar problem in obtaining low cost cabinets for their color TV and console units in volume. Initially, they obtained temporary sources of supply from Japan and parts of Europe. Increasing material, labor and shipping costs, however, soon eliminated these sources.

In their search for wood substitutes the furniture people presented to the plastics industry a rather impressive list of their requirements. For most items, the substitute was to be injection molded into the desired shape, painted to simulate a number of wood grains and then nailed, screwed or cemented to the cabinet or other structural surfaces. The material, therefore, must offer excellent moldability for fast cycling and fine surface detail, low cost and good lacquerability. Dimensional stability, toughness to withstand nailing, and rigidity, were also high on their list. Above all, however, these parts must look, feel and behave like wood.

Various grades of impact polystyrene were quickly accepted by most furniture manufacturers as the one class of materials which could meet their technical requirements at a reasonable material price.

At the start of this activity, several of the larger furniture producers utilized injection molded decorative components with caution. Consumer acceptance, manufacturing economics and long term serviceability were, at that time, unknown.

The first styrenes used in these test pieces were the usual grades of medium and high impact styrene. Later, the heat resistant impact grades were selected for basically two reasons: Their faster setup characteristics permitted shorter molding cycles with fewer sink marks and the resulting parts could resist warping or sagging during lacquer baking. Heat resistance in a molded part was very necessary since many parts were finished after attachment to the wood members and thus required exposures in paint ovens at 165° to 200°F for 1/2 to 2 hours.

Although most of the high heat high impact moldings now in use are meeting their individual application requirements quite well, a limited number of parts are now being produced which contain varying amounts of inorganic fillers. Supposedly, these are incorporated to impart sound deadening characteristics and to reduce sink marks in the molded piece.

An alternate approach to sound deadening is now being investigated which involves the use of foaming additives with high heat high impact polystyrene. Since this approach is relatively new and untried except in a few thick parts, it is difficult to assess the applicability of these semi-foam systems in furniture components.

Under the present distribution system, most styrene and other wood-like plastics moldings are being supplied to the furniture and TV manufacturers by custom molding shops across the country and in Europe. Invariably, the molded parts are trimmed and spray painted with a pigmented base coat prior to packout. As might be expected, the styrene pieces accept these ground coats very well. Using specially developed ink and lacquer systems, the furniture manufacturer can then assemble these to the wooden furniture frames and create any number of perfectly blended wood grains through dipping, wiping or spraying. These techniques, coupled with molded-in grain patterns, surface ticking, and "antiquing" result in parts which are virtually indistinguishable from wood itself. To improve the scuff resistance and general durability of the finish, the parts are usually spray coated with tough clear lacquer topcoats.

The extent to which polystyrene and other thermoplastics have penetrated the furniture market and other wood substitute applications is at this time difficult to assess. Until such time as consumer acceptance of plastics furniture components becomes more favorable, most observers feel that wood substitutions will progress rather quietly. The market for high quality moldings is there, however, and with the proper assistance from the material suppliers, molders and custom decorators, the furniture industry will undoubtedly expand their plastics applications with integrity.

MEAT TRAYS

A third area of high activity involving polystyrene has been in meat trays and related consumer packaging containers. Up until a few years ago, most prepackaged meats had been merchandized in coated paperboard or pulp trays which were then covered with various film overwraps to insure freshness. Although this type of tray was, and still is, very attractive in terms of price and durability, its performance was less than desirable. Basically, the objections to the pulp and low quality board trays centered around their tendency to absorb blood and other meat juices. Not only did this absorption tend to detract from the appearance of the package but it also necessitated re-wrapping by the housewife before she could freeze the meats. Failure to do so usually resulted in the meat freezing to the pre-wetted tray.

A third very important side effect of this absorption characteristic was that it represented a potential financial loss to the retailer. Under California law for example, a meat package must be priced on the basis of available product weight, and cannot include the weight of juices which have soaked into the tray since they are not available to the consumer.

The advantages of a non-absorbent plastics tray, therefore, were quickly recognized by many retailers - particularly by those operating in locales where this legislation was in force or under consideration. The first trays offered in large volume to meet this demand were formed from .100 to .160 mil polystyrene foam sheet. Shortly thereafter, lightweight, crystal-clear biaxially-oriented polystyrene trays were offered. The reception given both types was overwhelming, and for a while, market penetration was limited only by production capacity. Although each type offered a unique advantage over the other, both the foam and the clear tray provided non-absorbency, marked savings in storage space and a good combination of toughness with rigidity as compared to pulp. They also required no special heat sealing equipment nor did they impart taste and odor to the product.

The specific appeal for the foam tray seems now largely centered around price - about 25% less than the clear tray and comparable to pulp. It also has a clean, sanitary appearance which highlights the product quite well. The appeal for the clear tray, on the other hand, is centered on clarity which allows the housewife to examine both sides of the product prior to purchase.

Although most tray producers are reluctant to discuss the processes by which their trays are formed, it is generally believed that the majority are run on high speed pressure formers - possibly equipped with plug assist and in-place trimming mechanisms. Standard radiant heater vacuum formers are sometimes used in foam work but they can be difficult to handle. Reportedly, the forming range for unsupported foam is quite narrow, usually $\pm$ 5°F, and the slightest amount of excess heat can result in degeneration of the foam cell structure which will adversely affect surface appearance and strength of the resulting tray.

The grades of polystyrene used in both foam and biaxially oriented sheet for meat trays are invariably first quality high heat crystal products because of their characteristically low taste and odor properties. They also offer the ability to accept higher and more uniform levels of orientation stresses in biaxial sheet work. As with all non-pigmented standard polystyrenes, these grades conform to Food and Drug Administration (FDA) and Meat Inspection Division (MID) criteria for safe use with food contact.

In design, both trays are supplied in shallow draw, square shapes with raised or recessed patterns on the bottoms to catch or channel meat juices and to provide added stiffness to the unit. Bottom configurations usually include open slot, waffle, or rectangular patterns, and their structural advantages are particularly useful in the biaxially oriented clear trays which are formed from thin sheet in the 10 to 12 mil range.

The market penetration of the polystyrene meat trays is generally estimated at 10% of the published eight billion units used annually. Within this 10% figure, the foam trays are believed to have the lion's share at 9%. As more and more states adopt stronger Truth in Packaging legislation, the demand for non-absorbent, serviceable polystyrene trays will assuredly continue at high levels.

The future for the versatile polystyrenes in this application, in our opinion, looks extremely bright. Without a doubt, several new and equally exciting applications will select members of the polystyrene family during the coming year because of their unbeatable combination of price, performance and processability.

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PHENOLIC AND ALKYD ADVANCES

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The continuing growth that the thermoset segment of the plastics industry is experiencing is no accident. A great deal of ingenuity of both molding compound formulation and machine design has been employed to bring the state of the art to a point where the sales of phenolics have increased by 30% in four years, due in a large measure to the competitive cycles and reduced cost. We should note that these fast cycles are in part made possible by the fact that the curing of a thermoset can proceed at a faster rate than can the cooling of a thermoplastic. The industry has lost the big volume TV cabinets, the telephone handsets, and still continued to increase sales. This upsurge since World War II has had several milestones. The preheater made possible transfer molding (and the large part). Washing machine agitators, and more recently aerospace parts in the 40 to 50 lbs. range, have been produced in large volume.

Inserts were developed that could be pushed in after molding, thus making automation possible in redesigned parts (Figure 1). Cold powder automatic molding of motor control parts weighing 3 lbs. has come to be a commercial reality (Figure 2).

The emphasis on miniaturization and unit reliability has spawned thermosetting molding compounds with improved dimensional, electrical and thermal properties. It is of more than passing interest that glass-filled engineering thermoplastics carry only 105°C, UL rating without extreme testing; while phenolics, melamine phenolics, and melamines carry 150°C rating under the same system. Granular alkyds have been developed which run automatically in cold powder automatic transfer and in cold powder automatic compression. Their properties of insulation resistance (1×10^{15} ohms cm.); dimensional stability; resistance to thermal degradation; 13,000 psi tensile; and 20,000 psi flexural (after 1,000 hours at 400°F) have made them of interest to the electronic industry.

The arc track resistance has promoted their use in the motor control and automotive field (Figures 3 and 4).

The use of phenolics in the automotive ignition system (Figure 5) has long been established, but the new phenolics are opening tremendous new fields in transmission applications.

The reverse clutch cone (top of Figure 5) running in oil at 300°F - 350°F and molded from a glass-filled phenolic, is an example of a molded part outperforming the heavily machined die cast part it replaced. The tolerances of +0.000, -0.002"

on a 6-1/2" diameter can only be held by using a material with zero mold shrinkage. The part then stays functional over a range of temperatures as the material has the same coefficient of thermal expansion as the enclosing cast iron case.

The same material has been well accepted on oil pumping gears in automatic transmissions (bottom of Figure 5).

New transmission parts (Figure 6) include the oil collector (molded from a mineral-filled heat resistant phenolic). This part, when post-baked for 16 hours at 350°F, will be machined to 0.0003" flatness on the flange. The inserts will withstand 160 in.lbs. of torque. This transmission thrust washer in Figure 7 has the unique requirement of having to withstand 550°F without blistering. This part is molded completely automatically from a mineral-filled phenolic.

Perhaps it would be well to review methods for processing thermosets. In general, we have been placing relatively cold material into a hot mold and waiting for a chemical change to take place. With preheated preforms, automatic transfer presses have produced parts with 1/10th of an inch sections in 22 seconds (total cycle) of which 12 seconds was dry cycle.

A major breakthrough came when the thermoplastics people changed from a straight ram to a screw to preheat and inject material. This method was then adopted by Stokes and Rodgers for thermosetting compounds. The screw as they use it is a material handling and preheating device, and eliminated two of the biggest problems in a thermoset shop - preforming and preheating. The screw preheats the material and conveys it to the transfer pot, where a transfer ram pushes it into the mold cavities. At a widely quoted figure of 2¢ per lb. to preform general purpose material this can be quite a cost reduction.

In Figure 8 parts were produced on a screw press. Cures are dramatically reduced, but cycle times are reduced out of proportion to the amount of cure reduction. There is no fussing to get the preheat right, no variation of power factor or voltage drop. The problem of preheat variation due to hard or soft preforms, or variation in weight of pills to produce heavy culls or short shots is eliminated. Presses of this type, with horizontal platens, are ideally suited to the automatic degating and separating of molded parts, as very often several different parts are produced at once. This method of preheating has led to rather extensive insert work being done on these presses.

Either a shuttle type, or the very well received rotating dial, developed by Janler Tool & Die Co. of Chicago, is used (Figures 9 and 10).

As to the type of compounds that can be run in this equipment, as a general statement - if it can be run in a conventional transfer it can be run in the screw press. This means that plasticities, or flows, of 12 to 18 are usually used, although encapsulation grades of phenolic with a 40+ inch spiral flow have been processed.

Phenolics, urea, melamine, melamine phenolics, diallyl phthalates (DAP), and alkyds have all been run with ease. With alkyd and DAP compounds it may be necessary to keep the preheat temperature down to around 210°F in order to develop enough back pressure to cause the screw to back up on the softened material.

Long fibered asbestos, with a 1.4 ft.lb. of impact; nylon-filled phenolics; and 1/4" chopped glass rovings handle well if provision for agitation and/or a stuffer attachment is provided.

It is noteworthy that compounds which cannot be easily electronically preheated work very well on the screw. Such compounds as high dielectric mica-filled phenolics, graphite and metal-filled materials handle well as they are mechanically heated rather than electronically.

The next stage of the art involved the replacement of the transfer ram with a reciprocating screw acting as the transfer ram. This means an in-line press much like a conventional injection press, and it makes a further reduction in cycle time possible. These in-line presses, with vertical press platens, can by changing the screw design run either thermoset or thermoplastics.

The material producers believe that the new presses are the foundation of a brand new market area, because with the new equipment available thermosets are starting to replace thermoplastics due to the competitive cycles and reduced material costs. It is fine to say this, but it is better to have someone else recognize and back you up with dollars. The thermoplastic machinery manufacturer has started to develop presses and screws to handle thermoset compounds in the screw type injection equipment. So far, they are much like "old man river" - they must know something but they are keeping it quiet; however, by the end of this year at least six manufacturers hope to haveunits on the market.

With this new equipment available it is interesting to note that the wiring device, motor control and automotive manufacturers are moving twoard these new techniques. Today, appliance parts are produced in large volume; also, most encouragingly, the custom molders are starting to acquire this new type of equipment.

We have conducted extensive tests with standard ASTM molds in this new equipment, as compared to conventional transfer, and found that the values are (to all intents and purposes) identical. For a detailed study we suggest referring to the paper by R. W. Bainbridge in the SPE JOURNAL, Volume 22, No. 12, December 1966. As compared to compression molding, the flexural and tensile strengths are increased and the impact is reduced due to the restriction of the gates. The electrical properties are unchanged. The shrinkage in this type of molding is essentially the same as in conventional transfer. In general, transfer pressures are slightly reduced due to the more uniform and hotter preheats possible.

We should not get the idea that the screw type press is the best type of press for every molder. Many parts do not lend themselves to transfer molding. Cold powder, compression, or transfer may prove to be the most economical due to part size and the lower capital investment required. Certainly the plastics industry will have to face up to the new equipment and decide where it fits in best. There is a trend toward looking at existing applications and swinging them back to thermosets. Probably most of these jobs will have to be retooled to take maximum advantage of the outstanding properties of the thermosetting materials. Either way, I would like to leave you with one parting thought - there is no such thing as a "bad" plastics, only bad applications.

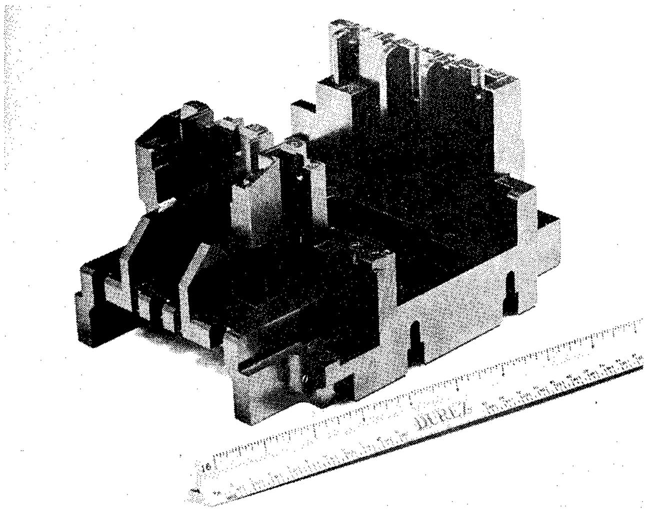

FIGURE 1

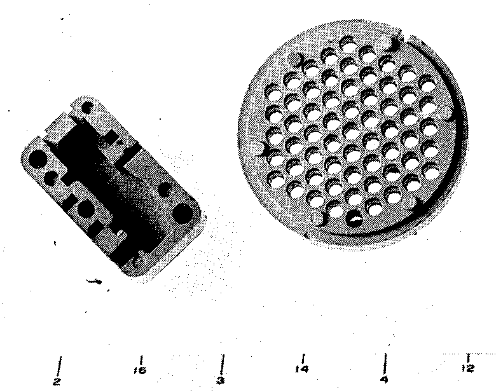

FIGURE 2

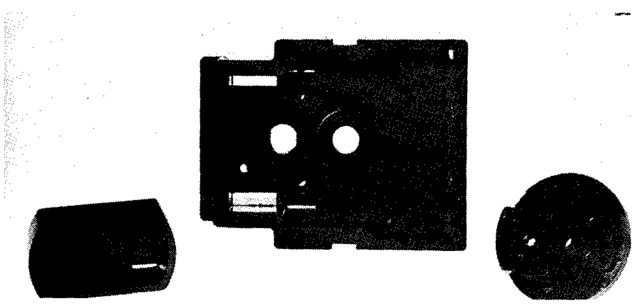

FIGURE 3

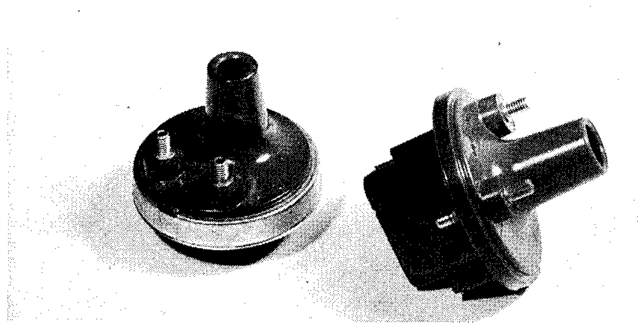

FIGURE 4

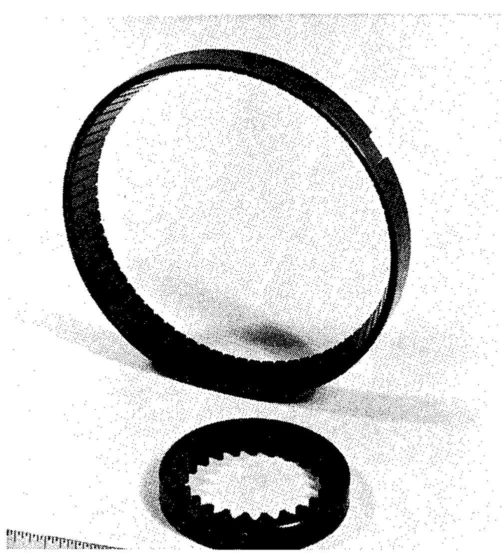

FIGURE 5

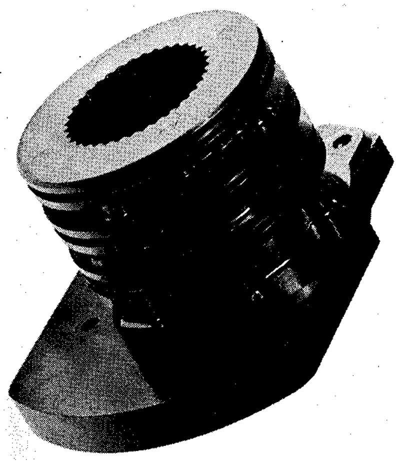

FIGURE 6

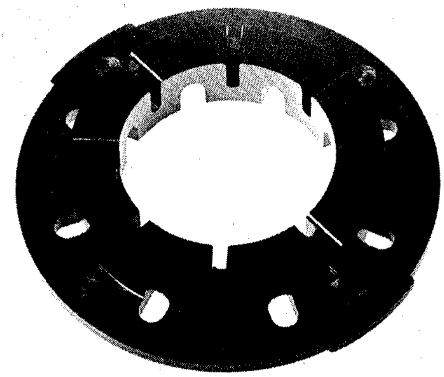

FIGURE 7

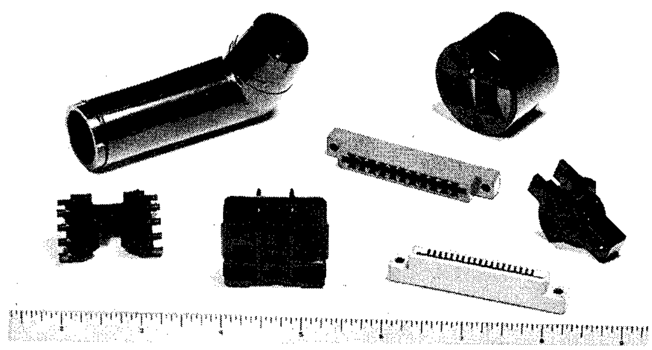

FIGURE 8

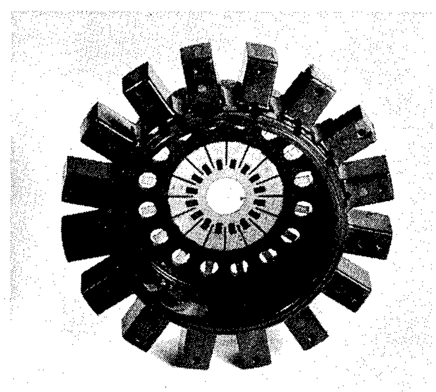

FIGURE 9

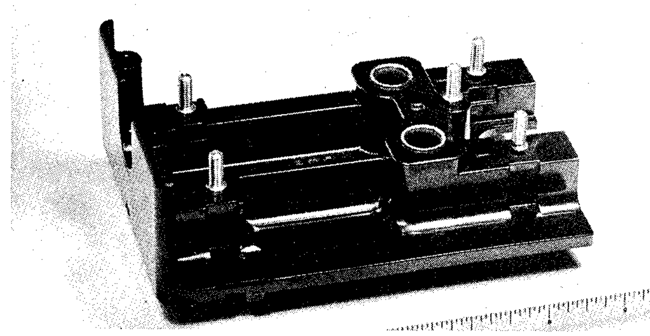

FIGURE 10

95785-15

COMPARISON BETWEEN PLUNGER AND SCREW

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The screw as a plasticating device, has been available, in this country, since 1961. In this five year period, the reciprocating screw has become the most popular type of screw of the several designs available. I am not going to argue the merits of the reciprocating screw, versus the in-line screw or the screw pot, as it has no place in this discussion. It will suffice to say that the reciprocating screw is sold at a 3 to 1 ratio over all the others.

It is also interesting to note that screw machines are selling at better than 90% of total sales, with the remaining 10% being plungers. This is somewhat misleading, as most of the plungers were on small machines, but this has been changed, with the advent of small screws for these machines.

The one place that the plunger is still superior to the screw is in producing a mottle, such as tortoise shell. The screw cannot reproduce the same type of mottle, but it can produce a mottle.

But why is the screw becoming so popular? What are the improvements that it is supposed to offer over the plunger? There are some of you sitting in the audience today, who are not convinced that you can't do as well with your plunger machines. In some cases, you can prove your point. But there are good reasons for this.

Part of this stems from the fact that the early screw machines did not have the benefit of a great deal of technology behind them. The American manufacturer of machines was pushed into producing screw machines by competition from abroad. Accordingly, they turned to the extruder people for help, for the most part, with only one starting from scratch to design their own screw machines. Sizing of the screw to the machine frame, was haphazard, at best.

The result of all this was machines that, in some cases, did not have enough torque, had slow recovery rates, limited plasticating ability and did not perform as well as a plunger machine on fast cycling jobs, such as containers. There was a further problem of education. This essentially was a case of trying to operate a screw machine in the same manner as a plunger machine. This will not work, as there are more controls on a screw that affect the plasticating ability and some of these controls will give the opposite effect that would be obtained on a plunger.

This, brings us to the purpose of this paper. To discuss the relative merits of the plunger machine and the screw machine, and their controls and their effect

on the operation of each.

We will consider first the plunger as it is the oldest device and the most successful, up to the advent of the screw. There have been other devices developed to replace or improve the operation of the plunger, but the basic plunger machine remains as the No. 1 type in use even today, even though a great many have been converted to screws.

In Figure 1 is shown a simple schematic of a plunger end, showing the plunger in the forward position and the shot has been made. Note that the next shot of material is resting on top of the plunger. This shot has been either measured by the volumetric device on the machine or has been weighed by a weigh feeder.

Figure 2 shows the same device with the mold open and the plunger back. The next shot has dropped down in front of the plunger and is ready to be pushed into the heating chamber.

Let us discuss this action in more detail so that we will be in a better position to compare this action as to that of a screw.

The shot is now resting in the shot sleeve in front of the plunger which is in the back position. The previous shot has been pushed forward into the rear of the heating chamber. This action of pushing in a predetermined amount of plastics pellets into the back end of the heating chamber forces a like amount of material out of the nozzle and into the mold. But what really happens? The heating chamber is so designed to contain from 5 to 12 rated shots of material at all times. That is to say, if the press is an 8 oz. capacity, the heating chamber will contain from 40 to 96 ozs. of plastics material. This large inventory is necessary because the plastics is melted by exposure to heat and not by any mechanical shear action, and it must be exposed for a long enough period of time to insure that it becomes melted.

To aid in the melting process, a device known as a spreader or torpedo is placed inside of the chamber to insure that the plastics particles will be as close to the heated metal as possible. The plastics material is a pretty good insulator and if the channels through the chamber are too thick, some of the plastics particles would not be melted. So the shape of the torpedo is very important. It must have good contact with the internal walls of the heater chamber to insure that the torpedo be close to the same temperature as the barrel itself. It must be shaped to allow the cold pellets to flow around the end without too much loss of pressure, and it must provide a small enough passageway toward the front to insure that the plastics particles come as close to the hot metal as possible.

At best, this is a whole series of compromises, because what worked well for styrene did not do as well for polyethylene or nylon due to the different heat requirements. It was not at all unusual to derate a heating chamber, by as much as 50% when molding a high crystalline polymer. The outside of the barrel was heated with electrical heating bands of various types, but essentially all types operated in the same manner. That is, by heating the steel of the barrel and thus the plastics by convection. It becomes apparent now why these chambers were designed with large inventories of plastics material. The larger the inventory, the longer the plastics was exposed to heat and the better chance of insuring a good melt. The heater bands were divided into zones, and most machines had two or three zones. Each zone was controlled with an on-off proportioning type of instrument.

Various types of control were employed to overcome melt temperature differ-

ences resultant from this on-off action. Some of these were to use two thermocouples - shallow and deep - and average them out. Others were the use of saturable reactor controls or variacs with pyrometers, in order to feed in a constant level of heat, as opposed to the on-off. On critical molding jobs where consistant melt temperature was required for flow, elimination of stress patterns, dimensional stability and the like, these controls did help. Needless to say, they were expensive and could not always be justified.

The added inventory in the heating chamber had the added problem of purging. The more material the chamber contained, the more difficult it was to change colors or materials, as the amount of movement of the plastics, shot to shot, through the barrel would reduce; hence, less scraping action. Color blending in a plunger machine was poor at best. This is why a plunger machine is preferred today where a mottle is desired. As the flow through the chamber was laminar, a given pellet could retain its identity all the way to the nozzle by the simple fact of tunneling. That is, the pellet would ride along in the center of the stream and never come in contact with the heated steel wall of the chamber or torpedo. Thus, because it was insulated by the plastics material around it, it would see considerable less heat and if a crystalline polymer, may retain its shape without melting.

Breaker plates were often used at the nozzle to improve color dispersion, and to help eliminate these cold pellets coming through.

But what about the controls available to the operator? The operator had two controls for the most part, and sometimes he had three. The two basic controls that he had were heat and pressure.

By controlling the various zones of heat, he could control the melt quality and the melt viscosity somewhat. We know, however, that the temperature of the melt stream at the nozzle could vary as much as 50°F. This variation depended upon the inventory of the heating chamber and the size shot and the frequency of cycle. The larger the shot size and the shorter the machine cycle, the greater the variation of melt temperature. The other control, of course, was pressure. This could be regulated to suit the injection requirements. The operator, then, had two controls to adjust in trying to fill the mold. If the mold did not fill, he could go up on pressure and if this did not do it, he would go up on heat.

The third control that was available on some presses was injection speed, or rate of fill.

All of this sounds great, except that there are inherent design weaknesses in the plunger machine, that are due to the nature of the beast. Because we are pushing a slug of cold pellets into the back end of the heating chamber to move the hot melt into the mold, several weaknesses show up. One is this slug of cold pellets. These pellets are constantly changing size and makeup as they are being exposed to heat so that the pressure being applied by the plunger is being partially dissipated by this spongy action. The second is the loss of further pressure due to forcing this cold and semi-cold material around and into the torpedo section. It is a known fact that we lose between 40 to 60% of the applied pressure on the material during mold fill.

In Figure 3 we see a time and pressure curve. Let us suppose that a given mold will fill at 7000 psi material pressure. Using the 50% loss factor, this means that the plunger is pushing at the rate of 14000 psi. As long as the material is flowing into the mold, this will hold quite steady, until we approach a static condition or mold fill. At this time the 14000 psi starts to become available, and the pressure on the melt will build up toward this but never quite reach

it because of the ever changing conditions on the plastics in the back of the cylinder.

This buildup of pressure could be very detrimental on many molding jobs and because of this, the machinery manufacturers came out with 2nd stage injection control back in the early 1950s. This provided a means of controlling this pressure buildup at the end of the plunger stroke.

Plunger speed or better still, displacement rate of the melt at the nozzle, was also adversely affected by this flow condition through the chamber. A machine that was rated for a 1200 in^3/min. displacement rate had in truth, about 600 in^3/min.

Yet, in spite of all these things, the plunger machine has, and is, doing a good job of molding. On many jobs, the plunger machine will do as good a job as a screw machine will do. This is because of the quality of parts required, and often because the mold was designed for a plunger machine and cannot take advantage of some of the benefits provided by a screw machine.

The industry tried several different devices to overcome some of the difficulties described above. To name a few, there was the preplasticizer which took many forms. The most popular and most successful was the piggy-back plunger - plunger type shown in Figure 4. Another was the melt extractor or polyliner shown in Figure 5. The most recent was the rotary spreader shown in Figure 6. All of these were developed to improve melt quality, improve shot control by eliminating the pressure and flow loss, improve shot weight control and increase the shot capacity in some cases, dependent on type of device.

Some of these have been carried over into the screw era by combining a screw with a shooting pot as shown in Figure 7 and the inline screw, shown in Figure 8.

However, the reciprocating screw has emerged as the most preferred device, today. Let us go on to this device and draw a comparison to the plunger machine that we were just discussing.

THE SCREW

Figure 9 shows a typical reciprocating screw. There is not much need to explain it, as most of you are familiar with it by now. So, instead of discussing the design detail, let us discuss the controls.

On the plunger we talked about the next shot being controlled by the use of a volumetric or weigh feed control dumping the next shot on top of the plunger. The use of any device to control the feed of material into the screw is not needed, as control of the shot is governed by the amount of material the screw plasticizes and deposits in front of itself. This is controlled by use of a limit switch which controls the length of stroke of the screw.

The plunger heating cylinder was heated using electrical heater bands controlled by two or three zones of instruments. The screw is also controlled in a similar manner, except that the plunger machine depended 100% on this heat, whereas the screw's dependence is determined by many factors - L/D of the screw, compression ratio, back pressure used, rpm of the screw, the material being processed, to name most of them. Each of these have an effect on the plasticating process and sometimes the heat is provided from the heater bands or sometimes it is provided by converting drive HP to heat by shearing the plastics or both.

So this is the first major area of difference. It is immediately obvious that one does not use the same heat profile on a screw machine that one used on the plunger machine. And yet, you would be surprised at the number of people who do this. There is no set rule for setting the heat profile for a screw, as the L/D, compression ratio and drive torque and rpm control have much to do with this. The manufacturer of the machinery can usually provide a profile for any given material.

A good rule of the thumb to follow, would be to set the front zone at the desired temperature of the melt. The center zone will usually be the same or slightly under this setting, unless it is a hard to process material or the screw unit is low on torque. It is necessary to use a higher setting in the center under these conditions. The rear should be somewhat cooler.

Let's be a little more general and say that screw of 14/1 or under use an inclining profile (rear to front). A 16/1 screw uses a slight hump profile (center higher than front) and over 16/1 uses a declining profile. It is obvious that the profile must be set for the screw involved and the material being processed.

It is apparent that the screw has far better control over the melt than the plunger machine. The melt is more homogenous than the plunger with practically no difference in temperature of the melt stream. This is because of the mixing and shearing action that takes place as the plastics is fed along the screw flights. This action makes for good color blending, good color or material changing with a minimum use of material, as well as consistent melt temperature.

The consistant melt temperature improves the molding due to improved flow. This brings us into another major area of difference. This is the area of injection pressure. You remember that we discussed the loss of pressure and flow experienced in a plunger machine due to the design of the beast. The screw does not experience the same problems for very specific reasons.

For one, the screw, as it comes forward as a plunger to force the molten plastics into the mold, is a full hydraulic situation. That is, the screw is pushing on a fluid (the melted plastics and not on the plastics pellets as on a plunger. Therefore, the pressure exerted on the hydraulic ram that pushes the screw is a true pressure.

Figure 10 is a slide similar to Figure 3 that was shown for the plunger. In fact, the black lines of the curve duplicate those of Figure 3. The red lines depict the same conditions for a screw. You will remember that the plunger machine had a 50% loss of pressure, which provided an upswing of the curve toward the end of the mold fill and the use of 2nd stage pressure prove a means of controlling the magnitude of this pressure use. On the screw, this upsweep of the curve does not occur, due to the almost 100% pressure condition. The only loss of pressure is due to friction of the screw and drive mechanism as it moves forward. This has found to be less than 10% and in most cases is not measurable.

This means that we have a flat line with no upsweep at the end. This means, of course, more absolute control over the fill pressure. You need only provide the proper pressure to fill. However, this is not the case. The upsweep of the curve on the plunger machine was beneficial to us on certain types of moldings. For example, let's take a television mask. This is a large thin section with bosses scattered around.. On the plunger machine, we had trouble filling this because of loss of displacement rate, but once filled, we did not have trouble with sinks as a rule. The same mold on the screw machine would fill very easily, but did not give good parts due to sinks. It was necessary to provide this buildup

of pressure at the end of the stroke, in order to densify the plastics in the bosses and thus eliminate sinks.

This meant adding independent second stage control. This provides the ability to raise or lower the injection pressure at some point during the injection cycle. With this control, we have improved on the plunger machine, even more, due to the ability to predict the pressure levels used.

The displacement rate is affected in the same manner as the pressure. Let us make a comparison using actual figures. A 12/16oz. plunger machine had a theoretical displacement rate of 1200 in^3/min. With the 50% loss, due to the nature of the plunger machine, we actually experienced a 600 in^3/min. displacement rate. The screw that replaces this 12/16 oz. plunger is a 22 oz. screw with a theoretical displacement rate of 1500 in^3/min. As explained earlier, there is no loss in this rate, so that the screw can actually displace the plastics at 2-1/2 times faster than the plunger.

This is very apparent when you take a mold that was designed for a plunger machine and place it in the screw machine and find that you can't stop flashing the center of the mold. This is because of this high displacement rate overpowering the mold. The screw machine is provided with an injection speed control, just because of this problem. It provides a means of slowing down the ram speed and thus control the displacement rate.

But let us review the various controls available on the screw. We will discuss these on the basis of using a general purpose screw and ignore the fact that special purpose screws can improve performance on particular polymers.

Melt temperature is a term used rather than heat because there are several things affecting the melt as explained earlier. The various controls affecting the melt are as follows.

Heat profile is important in that it must be set in conjunction with screw speed in order to get the screw back in the time allowed. Recovery rate is the term that we use to describe this action. The heat profile for your screw for various types of materials should be learned and a mold run card developed for any given mold to catalogue the various control settings.

Screw speed is important as only enough speed should be used to return the screw in the time allotted. The time allotted can be described as that portion of the cycle that the press is closed after the plunger forward timer times out. There is no advantage in getting the screw back as soon as possible. In fact, you have better control over the plasticating process if the screw is used for as long as possible. In other words, the screw should just get back to the switch and shut-off just before the press opens.

Torque is the amount of power available to turn the screw. There has been a lot of conversation regarding the various types of screw drives, electric or hydraulic. Actually, the screw does not care what drives it, as long as it is enough. The designer has the ability to put as much torque as he wants, dependent upon cost. There are pros and cons for each type and I will not discuss them here, except to say that the torque available governs the heat profile and speed used. There are available hydraulic drives that provide a selection of torque to suit the various types of materials processed.

Back pressure is a very important control as it causes the screw to work harder in preparing the melt. It is possible to increase melt temperature by over

$50^{o}F$. by adding back pressure and not change the heat profile or speed. It helps to eliminate weld lines in the molded part by improving the melt condition. It does slow down the recovery rate of the screw, however, and should be used with discretion. It is important to the melting ability of the screw and one should become knowledgable in its use.

Injection speed, as explained earlier, displacement rate on a screw is different than on a plunger and one should become familiar in the use of this control. If lower injection pressure, to the point of non-fill does not eliminate flashing, then the use of a slower injection speed is required.

Never use the same injection pressure on the screw as used on a plunger machine as flashing will result. Always start with a low pressure and work up. The previous explanation and chart portrayed this problem.

Non-return valve has not been discussed previously as I consider this to be part of the general purpose screw assembly. This is a valve placed on the end of the screw to prevent the molten plastics from flowing back into the screw flights on injection. Figure 11 shows two views of a typical ring type valve. This one view shows the ring in the pumping position and the other view shows the ring in the shooting position. In order to get good control over injection pressure, one must have a good operating non-return valve. This has been a source of trouble to all machinery manufacturers. This is due to many factors. For one, it is an area of compromise. The diameter of the screw limits the designer on the physical size of the valve, the size of threads used, etc. It is also subjected to considerable wear conditions during pump back and this wear is dependent on the type of polymer being processed. The easier flow material, the less wear. The harder flow, the more wear. In short the valve must be considered as a replacement item.

Impulsing is a means of hydraulically moving the screw backward for a short distance after injection in order to decompress the material in front of the screw. It can be done either in the forward position of the screw or at the rear position. The type of mold and material govern when and where it must be used.

In general, where the plunger machine had three controls over the melt process and injection, the screw machine has six. The use of all six are important. Earlier I said that the operator had two controls to use in filling the mold. If the mold was not filling, he would go up on heat or pressure or both. In a screw, if the mold is not filling, going up on heat does not necessarily improve melt quality, but will slow down screw recovery. Going up in pressure probably will not help if the stroke control is not set properly and the screw is bottoming out. One must define why the mold is not filling and then adjust the proper controls. It is more involved than the plunger for sure, but once one understands, he can do so much more with it. It is a matter of educating your people on the various controls and their impact on the molding process.

It is a matter of record that the screw is the best plasticating device available to the industry today. It is going to be with us for some years to come. There is much work to be done by the machine manufacturers on improved screw design, both for general purpose as well as special purpose. There is a great deal of technology to be developed, both by the machine manufacturer and by the molder himself. I am sure, that working together over mutual problems, this device is going to be better than it is today.

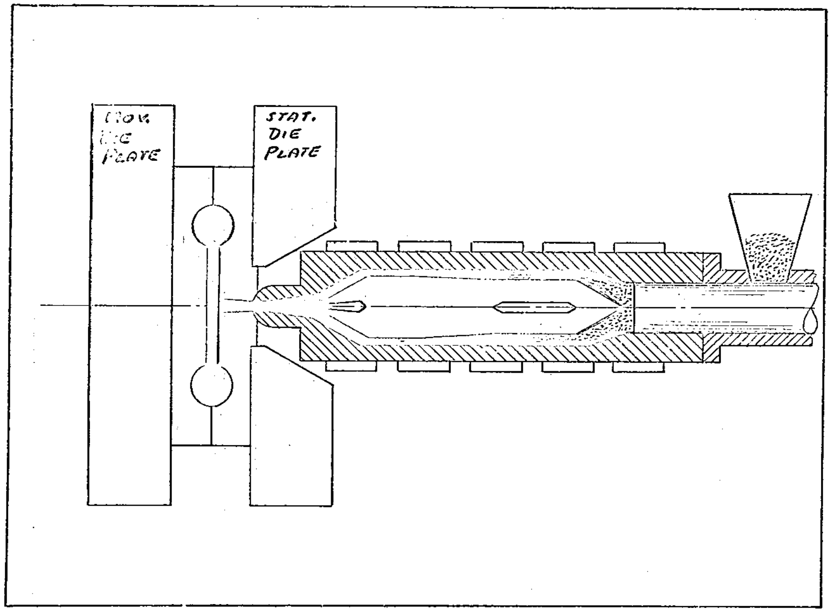

FIGURE 1

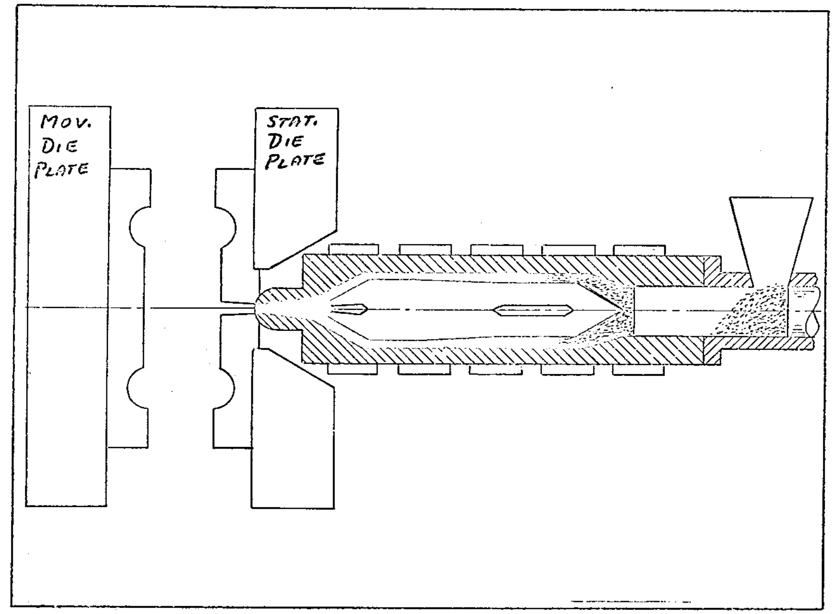

FIGURE 2

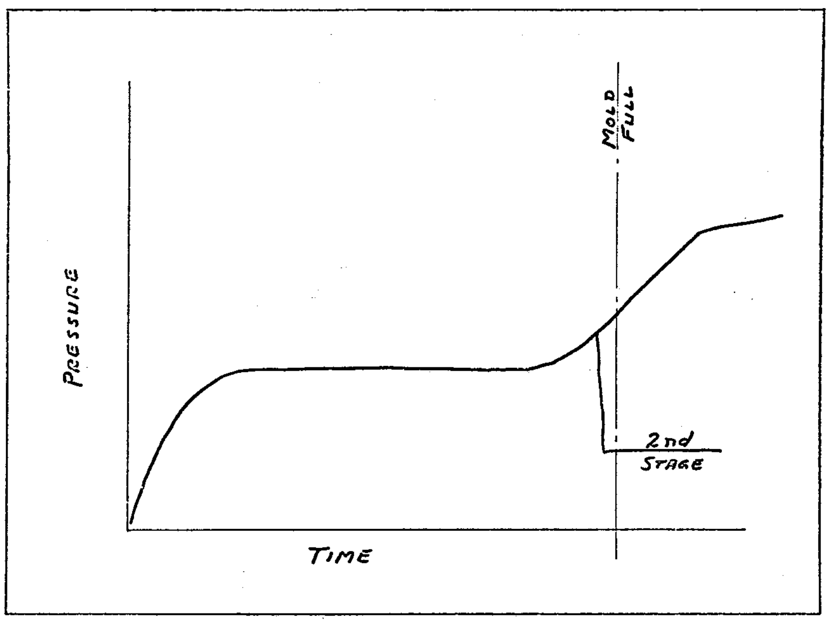

FIGURE 3

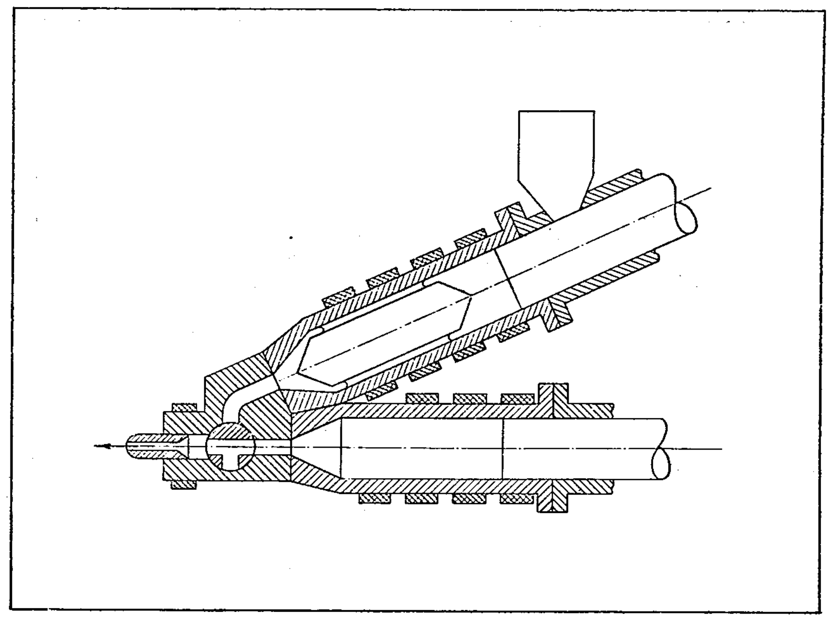

FIGURE 4

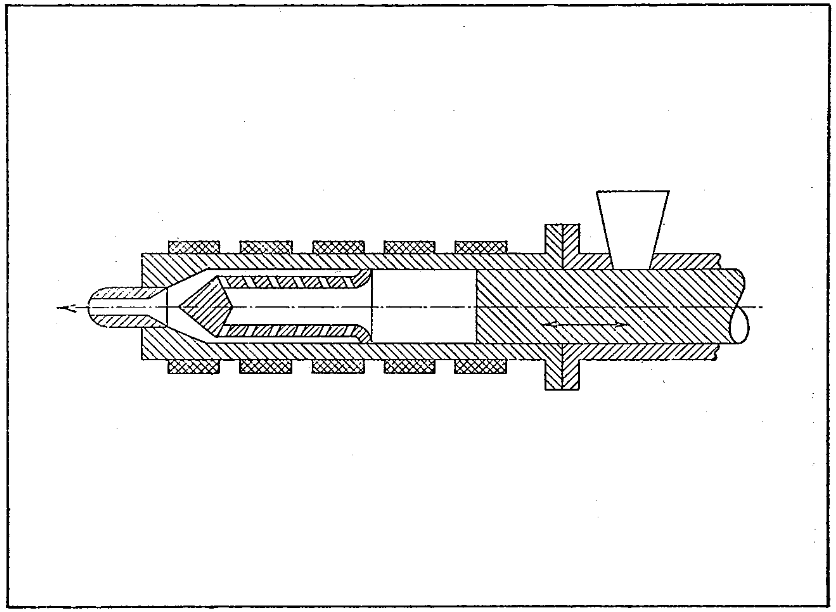

FIGURE 5

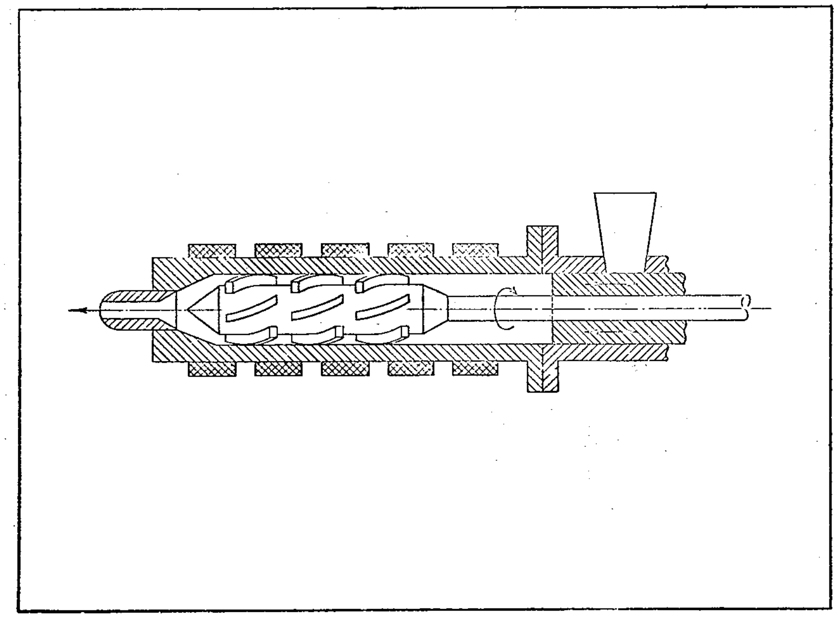

FIGURE 6

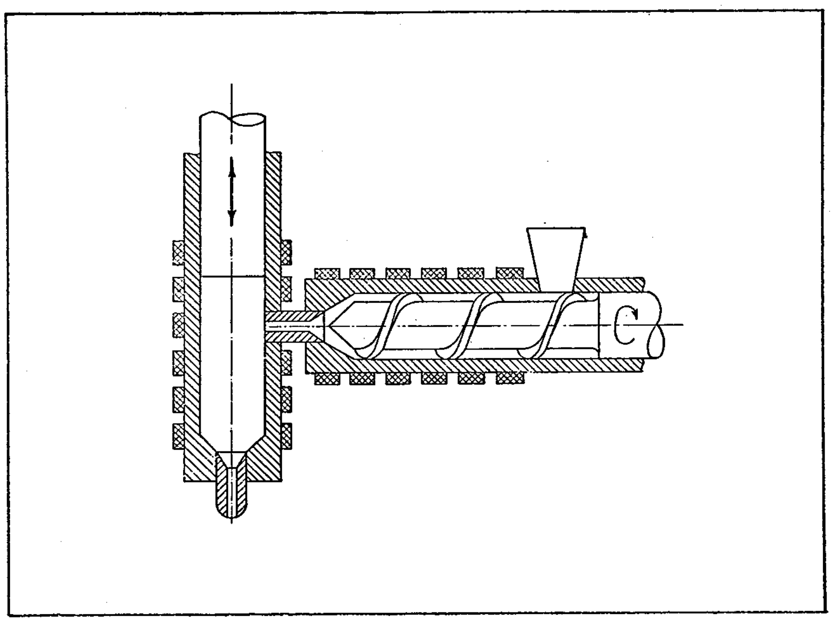

FIGURE 7

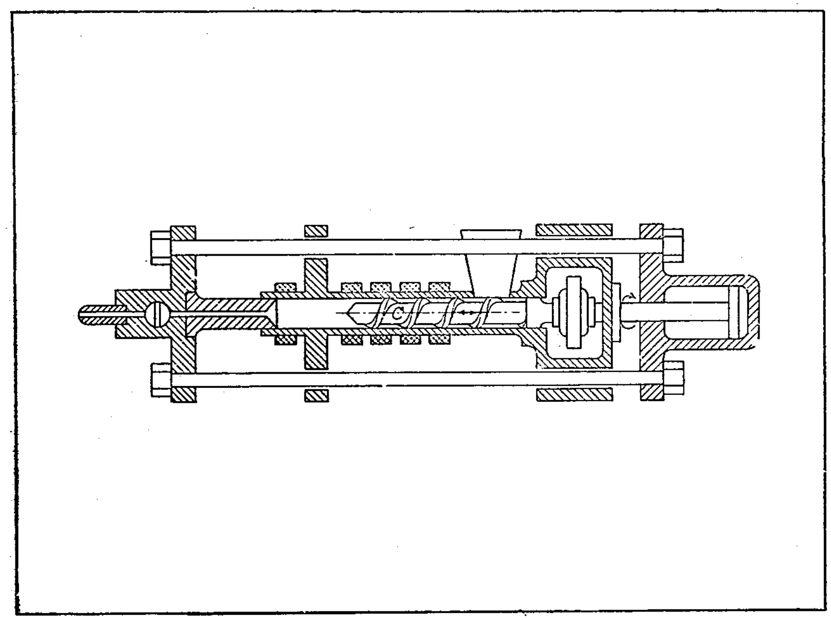

FIGURE 8

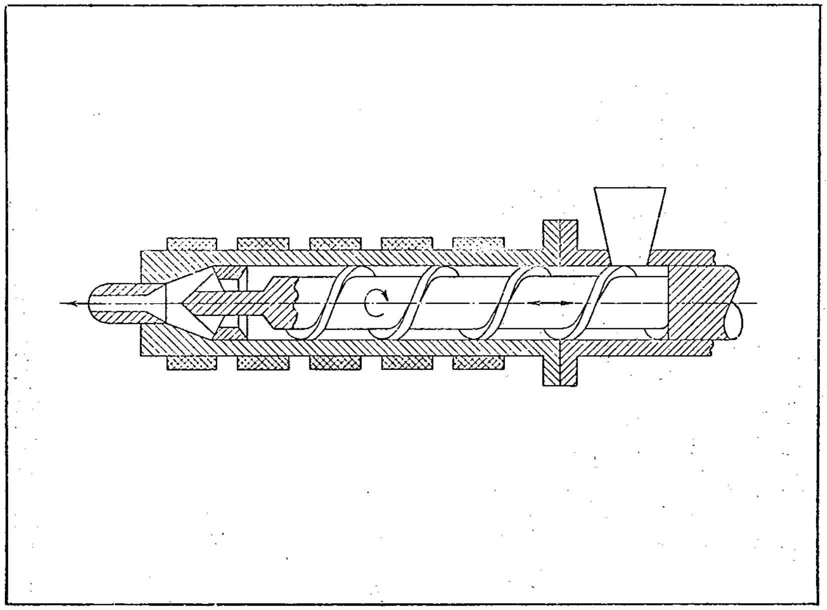

FIGURE 9

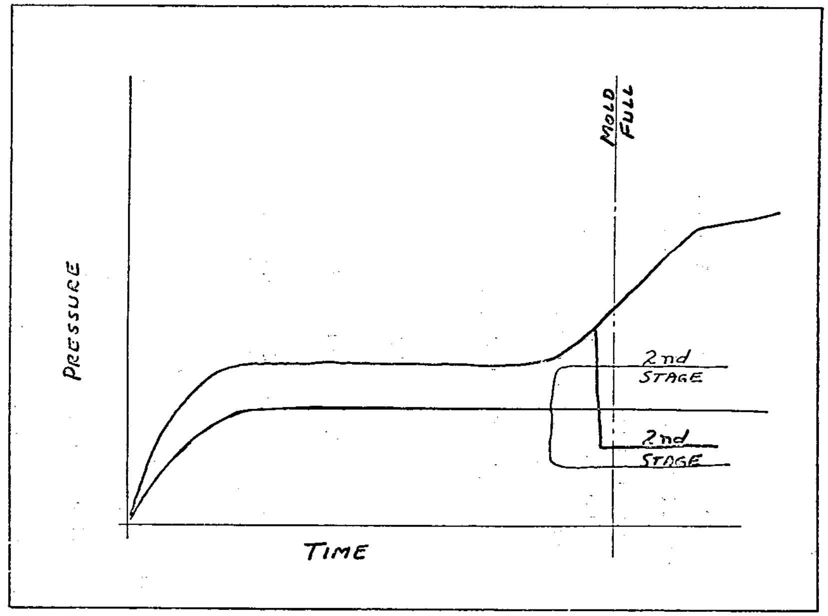

FIGURE 10

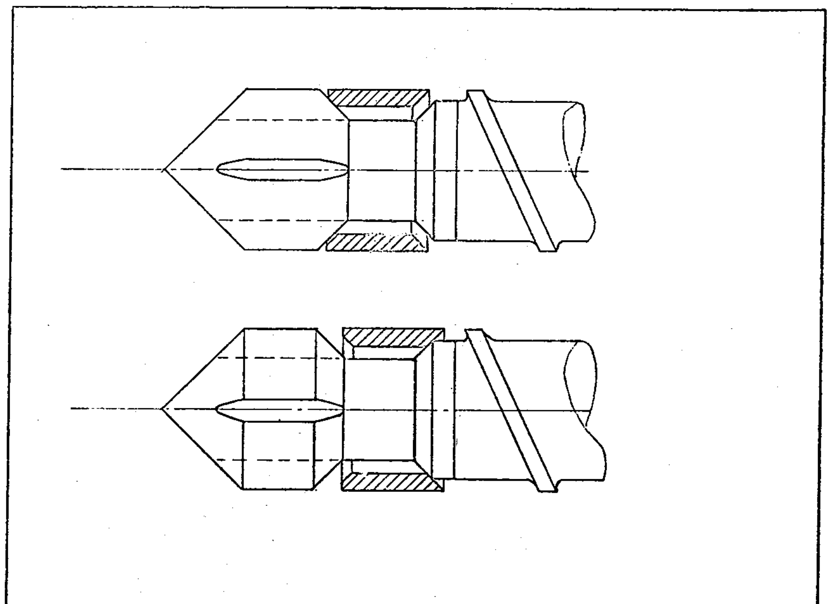

FIGURE 11

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THE INJECTION MOLDING MACHINE ELECTRICAL CIRCUIT

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The modern injection molding machine is a rather complex piece of equipment when compared to the original concept of the movable die plate and injection plunger. But today's complete machine must be considered a well organized arrangement of the mechanical, hydraulic, pneumatic, electric and electronic sciences. Yesterday's simple motions of the die closing and the plunger injecting have been replaced by experienced requirements of faster cycles, increased safety, precise programming, accurate control, varying stages of pressures, fast and slow traverse actions, emergency features, stop motions, decompression, nozzle shut-off, coring, hydraulic ejection, and the low pressure die protection. These are only a few of the basic requirements for injection molding machines. Add to this the SCR and saturable reactor control of heat, solid state control, and the JIC Standards, and you will begin to see why it is so important to get a review of the basics or a thorough understanding of the fundamental electrical circuit.

Our main purpose therefore, is to provide information and instructions whereby the maintenance man or electrician can properly understand, maintain, modify, or trouble-shoot the electrical circuit of an injection molding machine in the quickest amount of time and with the guidance of only the electrical diagram. To reach this goal we will explain and discuss the following five steps:

1. The function of the control system.

2. A description and explanation of the electrical devices, symbols, and operation.

3. Basic principles involved in reading and understanding wiring diagrams by an equivalent circuit.

4. Examining the typical injection molding machine's circuit.

5. Trouble-shooting.

FUNCTION OF THE CONTROL CIRCUIT

Where mechanisms, hydraulics, and pneumatics form the muscle power to move the major elements of a machine, the electrical system serves as the nerve and memory system to control the loads and limit the action and position of mechanisms.

Through the control circuit we sense temperatures and positions, detect overloads, program each phase of a cycle, and set up the memory for each portion of a

cycle. This, then, is the purpose of the electrical system - to sense, program and control.

Naturally, in order to design and engineer this programming, to determine the requirements of devices, to lay out the plan or scheme for intercommecting wires between the machine and enclosure, to record the sequences of operation which would serve as a means to maintain, modify, or trouble-shoot, we must have a sketch or diagram. But a diagram is a means by which one can depict and represent devices in a simple or symbolic form and still maintain a reasonable pictorial semblance of the devices.

This, then, leads us into the next step - explaining electrical devices, their construction, operation, symbol and function within a control circuit.

FUNDAMENTALS OF ELECTRICAL DEVICES

A. Relays

One of the most important tools an electrical or control engineer has at his disposal is a relay. This is a device used basically as a means of switching control circuits from one function to another. As a single element, it has little value, but used in conjunction with sensing, detecting, timing, or manual operations, it is most versatile. There are a great many designs and styles of relays used in the control circuits of industrial machines, computers, instruments and thousands of other devices. Irregardless of their application, the purpose is always the same - to switch the function of a control circuit.

The relay is composed of a coil, a magnet structure, an armature, and a set of contacts connected to the armature or plunger. The contact structure consists of two forms; a normally open type of contact and a normally closed.

By the term "normally open" contact, we mean that the relay in its de-energized position, that is, with no power applied to the coil, would have a contact in the open position. This contact would remain in the open position until a current is applied to the coil, energizing it, and through the magnetic action cause the contact to "make" or close.

Conversely, a "normally closed" contact means that the contact is in the closed position at rest and will remain in such position until the coil is energized, causing the contact to "break" or open. So then, a "normally open" contact closes when the coil is energized, and a "normally closed" contact opens when the coil is energized.

Now let's examine how this energizing action occurs. It was stated that the relay consists of a coil, a magnet structure, an armature and a set of contacts. The coil is made up of hundreds of turns of very fine wire wound around a spool. When an electric current is applied to the wire, magnetic lines of force radiate in a torridal ring around the coil. In order to control these lines of force and direct them into a stream or path for greater and more efficient usage, a soft iron core or magnet structure is placed around the coil. Since we wish to derive work from these lines of force, an

armature or plunger is also designed into the structure and connected to a cross bar or contact arm in order to produce a motion whereby a position change or switching action can take place. Whether we are talking about the industrial type of relay that has a large magnet structure or the telephone type, the construction is basically the same. Functionally, by energizing the coil, we change or switch the normal contact position.

Relays can have any number of normally open and normally closed contacts. The most contain no more than 8. The contact rating of industrial type relays vary from around 3 amps to 10 amps, which is determined by the relay design and the size of contact. On injection molding machines, relays are used to switch the control function of the machine cycle by switching the action of other relays, solenoids, timers, pyrometers, etc.

B. Contactors

Contactors are devices which are similar to relays in general appearance. Their purpose also is to switch circuits, except that unlike relays, they are designed to carry heavier loads or currents. As a rule, contactors contain only normally open contacts and the standard number of poles obtainable is 1 to 4. They, too, have a coil, magnet structure, armature and contact bar. Since they carry larger currents, they also have arc shoots or barriers which are used to quench the flash that occurs when a contact makes or breaks. Contactors are usually sized according to the number of amps that the contacts are designed for. For instance, a size 1 contactor carries approximately 27 amps.

Since heater loads are large, we must switch wattages ranging from 1,000 to 15,000 watts per zone. Therefore, we must resort to the heavier switching device which is the contactor. Physically, the only difference between contactors for switching large or small loads is their relative size. Operationally, there is no difference between the contactor and the relay.

C. Magnetic Starters

Magnetic starters are devices used to control the starting and stopping of motors. Like the contactor, the contacts operate when the coil is energized. The contactor is used in the assembly of a magnetic starter. However, since the motor must have a means of protection against internal heating due to excessive over loading, sensing devices which detect higher currents than should normally be allowed are attached to the contactor and in series with the motor. These devices are called overload relays and they are the only major difference between a contactor and a magnetic starter.

The overload relay is a unit which holds an overload heater element and a small set of contacts. The heater element may be a bimetallic strip or a solder pot and spindle. In either case, the action is such that when the heater element heats up due to excessive currents, it causes the relay contacts to open, thus de-energizing the starter coil and opening the load or motor contacts. There are usually two overload relays on each starter.

Like the contactor, the starter is capable of carrying heavy currents and is sized according to the current rating of the particular motor it is controlling.

So far, we have discussed three devices - the relay, the contactor and the starter. We have discussed these together because their function, construction and operation are so very similar. Since they are so similar and since we must portray the devices in some pictorial or symbolic form for easy identifiable representation, we can break down the respective devices into their major electrical components such as the coil, the contacts and the overload elements.

In the standard industrial symbolic form, the coil is represented by a circle. The normally open contacts by two small vertical lines. Since normally closed contacts are only a modification or condition of the normally open, they are represented by two vertical lines crossed by a slanted line.

D. Solenoids

Solenoids are devices used to obtain a straight line motion. Most solenoids fall into a group with less than 1" stroke. However, heavier duty industrial types are available for larger strokes. They may be available in either the push or pull type or with a double solenoid assembly. The solenoid is made up of a frame, a plunger and a coil. When the coil is energized the plunger will move, similar to the action of the cross bar and contacts on a relay. On injection molding machines, solenoids are used with valves to move the valve spool from one position to another.

When a solenoid is energized, it is important that its plunger complete itsstroke, otherwise the amperage in the coil will be high and will result in damage to the coil.

Current in amperes at its maximum stroke is referred to as "in-rush current". Current in amperes at the closed position is referred to as "sealed or holding current". In a small solenoid, the ratio of in-rush current to sealed current is approximately 5 to 1.

The pull of a solenoid must at all times exceed the load. If the pull is a little less, the solenoid action will be sluggish and may not complete the stroke. In the case of solenoid operated valves as used on injection molding machines, such an action would mean that the valve spool would not complete its stroke, thereby preventing oil from passing through its proper pressure or tank port.

E. Sensing Devices

With automatic machinery of any type we must utilize various types of signal and detection devices to cause the magnetic control to properly cycle and operate their respective loads. These devices are found in many forms, but their function is always the same - to signal a change in operation. There are limit switches to detect position, pressure and vacuum switches which indicate the high and low pressures or vacuum levels, flow switches which detect liquid leveland temperature actuated switches which sense heat.

Limit switches are made in many styles and forms which vary from the very minute as used in electronic and computer work to the massive steel mill type. Regardless of their size or type of operator lever, their purpose and function is the same; namely, to cause a change in contact action when the plunger or lever is tripped by an external cam motion. Limit switches generally contain a normally open and a normally closed set of contacts. Some forms of limit switches may have two sets of normally open contacts operating from a neutral lever position. The contacts may be the independent circuit type or single-pole double-throw with a common connection. But regardless of its contact configuration, the function and operation is always the same.

Symbolizing the limit switch requires a little more thought than a relay or other types of switches. The reason is that with limit switches, we are not only concerned with the normally open or normally closed contacts, but also whether or not these contacts are being tripped while the machine is in its "at rest" position. The proper symbol reflects the circuit condition on the wiring diamgram with the machine "at rest".

In addition to the commonly known lever operated limit switches, two more types have been introduced to the market in recent years. One is called a proximity switch and the other a vane switch. The proximity switch consists of a sensor which is the operating means and a separate transistorized amplifier. The sensor detects the presence of material without direct contact. The signal is sent to the amplifier which in turn operates a relay. The contacts of the relay then perform the same function as the lever operated contacts in the conventional switch.

One advantage of this type of switch is that the sensor can be located remotely from the amplifier, up to a distance of several hundred feet if necessary.

The vane operated limit switch is actuated by the passage of a separate steel vane through a recessed slot. As the vane passes through the slot, it changes the balance of the magnetic field, causing a contact to operate. The contact portion of the switch consists of a Reed type device. It has a single normally open or normally closed contact. This switch can detect very high speeds of vane travel without detrimental effects such as arm or mechanism wear or breakage.

In addition to the limit switch type of sensing device, there are many other switches used for definite purposes or conditions. For instance, there is a liquid level switch which would operate in a tank and detect or control the limits of a liquid. There are vacuum and pressure switches which control on the rising or falling of pressures or vacuums. There are temperature actuated switches and there are flow switches. In all cases, the electrical contacts are actuated through some form of mechanical linkage. With the pressure switch, it's through a valve poppet. A liquid level, through a fulcrum linkage. A temperature actuated switch operates through a bi-metallic strip.

All of these switches have a basic contact symbol. The characteristic nature or definite purpose usage is reflected as an added

part to the symbol.

F. Pushbuttons and Selector Switches

Where limit switches, pressure switches, etc., are all used to control, signal and detect the operation automatically, there are also necessary functions that must be operated manually to set up certain conditions. These are referred to as pushbuttons, selector switches, transfer, rotary or pilot switches. In essence, the selector, transfer, rotary, or pilot switches perform the exact same function. Only the physical construction differs.

A pushbutton can be of the momentary or the maintained type of operation. A momentary type makes or opens a contact when the button is pressed, and released when pressure on the button or operator is released. The maintained contact type "makes" when pressed and remains in such a condition until released by pressure on another button through a mechanical linkage.

The construction of a pushbutton consists of an operator and a contact block grouping. The oil tight type of operator contains the button and a pushrod. The buttons are available in various colors, with flush, extended or mushroom heads, locking attachments, rocket arm lever and wobble stocks. Contact blocks consist of one or two sets of stationary and movable contacts arranged in such a fashion as to provide normally open and normally closed contacts. The movable contacts are connected to a bar which through plunger action, moves when the button or operator is pressed, thereby closing the normally open and opening the normally closed. In the case of the momentary type, its spring action returns the contact to the normal position after pressure is released.

The contact action of selector switches is the same as pushbuttons except that turning the selector switch operator opens or closes the contacts through a cam action. Like pushbuttons, selector switches can be maintained from any set position or spring returned to an initial position.

G. Timers

Timers are a form of control used in process programming to signal elapsed time of a cyclic sequence. These devices are made in many forms and operate through principles of springs, pneumatic bellows, dashpots, synchronous motors, or electrical discharge. The type of usage, precision and time delay would normally govern which timer would be most adaptable for the particular operation. The spring wind-up type is not used in automated designs. The pneumatic bellows type can be used where merely a time delay is required without close accuracy, remote setting or accurate dial control. The electronic timer is tops for precise repetitive accuracy especially in the small time ranges. Where time settings of 3 to 150 seconds is required, along with external dial settings, fair repetitive accuracy, and where simple repair and maintenance is allowable, the synchronous motor timer is the most economical. These devices consist of a motor, clutch, solenoid and contacts. Through gearing, the device starts timing, at the completion of which a set of contacts trip. The timer remains in the tripped position until reset by the

electrical circuit.

Time delay relays or pneumatic timers can perform two types of action. They can perform a contact delay action when the coil is energized, or a delay action when the coil is de-energized. Both types of action are necessary for many automatic applications.

Timing contacts have special symbols. Since there are requirements for both a delay on energization and a delay on de-energization, separate symbols must reflect this type of action.

H. Pyrometers

On many of today's processing machines, heat plays a major role. Along with heat, there must be a good, accurate type of control. One of the most versatile and efficient control instruments is the pyrometer. This unit responds through the basic theory that an EMF is produced at the cold end of two dissimilar wires when heat is applied to their bonded hot junction. This EMF is amplified and actuates a meter element to move an indication pointer across a calibrated scale. If the pointer is below a set point, electronic action within the instrument energizes a relay which, through external circuitry, causes the heaters to energize. When the pointer has reached the set point, the relay de-energizes, causing the heaters to de-energize. It is through this ON and OFF action that the pyrometer controls heat within very minute limits. Since a straight ON and OFF action can cause overriding due to heat inertia, more formidable anticipatory and proportioning types of devices are available. These devices tend to smooth out the action and control around a more level temperature. For even more precise control, the new SCR or saturable reactor types are recommended. These types control in such a way as to furnish only that amount of power to maintain the temperature.

I. Heat Sensors

There are three different types of sensors used in the pyrometric control of heat. They are the thermocouple, the thermister and the resistance bulb.

The thermocouple consists of two dissimilar wires joined together and welded at one end to form the hot junction. Heat applied at this junction causes a usable EMF at the cold end. For protection, the wires are put in a metallic tube. It must be remembered that the only sensing portion of the thermocouple is at the tip, and for that reason, the end must be in firm contact with the surface being measured. If a thermocouple is inserted in a drilled hole and the couple does not bottom, an air barrier is set up between the thermocouple and the surface being measured, forming an excellent insulation which will produce erroneous results at the pyrometer.

Thermocouples can be used to sense up to 5000°F. Various metals are used for sensing in the different ranges. Such metals as copper-constantan, iron-constantan and chromel-alumel are used in thermocouple construction.

A thermister is a semi-conductor whose resistance decreases with

increasing temperature. This element is connected to a Null reading type AC bridge circuit and the output fed to an amplifier. The output of the amplifier operates a relay that is used in the control circuit.

The resistance sensor consists of a tube made of stainless steel or brass which contains an element made in the form of a coil. The coil is wound with a fine nickel, platinum or pure copper wire. As the temperature of the coil changes, the resistance changes proportionately. The resistance is converted to a voltage in the control circuit. Therefore, as the voltage changes with a temperature change, the voltage is compared to a reference, and thus an output proportional to the temperature change is obtained.

J. Heaters

On injection molding machine applications, the barrel heater bands are generally made in two halves and clamped to the cylinder or barrel with a strap or clamping device. Being in two halves, each half heater would have its own separate winding. If the heaters were connected together in series, the voltage applied to the terminals would be twice the voltage that each half is wound for. For instance, two half bands wound for 110 volts would accept 220 volts at its terminals. If each band were wound for 220 volts, then power would have to be applied independently and in parallel to each half band. With sufficient terminals, heaters can be wound for 220 volts and through series or parallel connections, at the terminals, either 220 or 440 volts could be applied. This would eliminate the necessity of changing heater bands when a machine is moved from one location to another or if the power supply at the plant where changed.

K. General

There are a few other devices used in control work of which we will not go into descriptive detail. They also have symbols representing the device. As the chart in Appendix A indicates, disconnects, circuit interrupters and circuit breakers all have a different symbol. The basic purpose of each is the same; namely, to disconnect the incoming power source from the machine. Transformers, rectifiers, fuses, etc., also have their own symbol. Understanding these symbols is a basic requirement toward the reading of wiring diagrams.

PRINCIPLES OF A WIRING DIAGRAM

Discussions regarding devices, their construction, operation and use, together with recognized symbols, have been a prelude to the explanation of wiring diagrams and their interpretation.

Wiring diagrams are the tools and the key to the proper sequence, control and assembly of all electrically operated devices on a machine. They are the engineer's design layout, the electrician's assembly drawing and the maintenance man's trouble-shooting guide. Since they serve these functions, they must be in a form that can be interpreted with a common understanding. The engineer in initially designing the circuit cares little as to where the wires or devices are

physically located. His main objective is to arrange components of devices so that they function electrically with respect to each other. On the other hand, the electrician is interested in knowing the physical relative location of each device and how the wires are connected between them. The maintenance man wants to be able to quickly analyze the circuit from the standpoint of faults and then physically trace and locate the trouble or be able to use the circuit for new additions or modifications.

For these reasons, a good wiring diagram is broken down into an elementary or schematic diagram, and an interconnection or machine diagram.

The elementary diagram is the true source of operational and sequencial information - the engineer's or designer's working drawing. It is a simplified line drawing showing the necessary device elements in their proper electrical location, as a functional relation to each other in the circuit rather than a physical arrangement. A relay coil, for instance, may be shown in its correct electrical position and be far removed from the contacts operated by it.

The elementary diagram forms the basis for designing the control. It is a common meeting ground between the machine designer, control engineer and trouble shooter. Since it is an elementary diagram, simplicity is most important; simplicity through form and design of circuitry, simplicity through representation of devices.

Along with symbols, there are standard device designations. Device designations are intended for use on wiring diagrams along with a corresponding symbol to indicate the function of the particular device.

These are the tools by which the elementary diagram becomes the most important piece of information for understanding the function of the control system.

The interconnection diagram is a pictorial layout. It shows the control panel with all devices such as relays, starters and fuses in a physical location with respect to each other. It shows all other devices such as pushbutton stations, limit switches, timers, solenoids, heater, etc., in their relative location with respect to electrical assembly. In some way, either by connecting lines, harnesses or by wiring tables, there must be an indication as to how all of these components are interconnected to complete the physical circuitry.

The interconnection portion is primarily for the manufacturer's electrician wiring the machine and the user's electrician to locate devices, trace wires during trouble-shooting, or making modifications. In other words, it is a complete wiring map.

Such is the working portion of a wiring diagram. These are the instruments, the elementary and the interconnection diagrams, which can be used for trouble-shooting or making modifications. That is, of course, if one knows the complete machine operation thoroughly and is able to retain this memory. The important point to be made is that regardless of how elaborate or complete the elementary or interconnection diagram may be, its worth is minimized unless suitable supporting information is presented either on the drawing or on supplemental sheets.

Such supplementary information should include:

1. A material list. This ties together the device by its designation, description and catalog information.

2. Limit switch operation. This is always an area of doubt or question on any machine as to when a limit switch trips or releases. A legend of limit switch operation is an invaluable bit of information for the trouble-shooter or maintenance man.

3. Sequence of operation. Regardless of how exceptional or talented an engineer or electrician may be at reading or deciphering wiring diagrams, if he does not understand the physical machine action, together with the electrical resultant, the wiring diagram has lost much of its value as a useful analysis media. A complete description, therefore, is very important as a timesaver and as an added means to communicate thoroughly.

Operational information on a wiring diagram is not only good practice from the standpoint of understanding new or existing machinery, but it is most valuable for those obsolete machines when ready information or knowledge is not available. To the engineer or designer, it is handy quick reference material for reviewing the machine operation. For the user, it saves much down time when a fault occurs.

Now that we have explained the purpose and requirements of good wiring diagrams, let's try to understand how to read and interpret them.

Strangely enough, a simple circuit represents the basic principle involved in reading, interpreting and understanding wiring diagrams. The two lines from the plug represent the power lines, the switch represents the signal device and the light represents the load. All control circuits revolve around these three functions - power, signal and load.

Anyone can understand this circuit. If the plug has power, closing the switch completes the circuit from L1 through the light to L2. Opening the switch breaks the circuit between L1 and L2, de-energizing the light.

Trouble-shooting this circuit is also simple. If closing the switch does not energize the light, the first thing to check is whether or not the plug is connected, or in other words, whether there is a voltage between L1 and L2. The next device to check is the load or light bulb to determine whether it is burned out or not. Third, is the switch functioning properly, and fourth, check for broken wires or loose connections. The discussion of this basic circuit is equivalent to that of any wiring diagram. The same reasoning is used throughout to analyze and trouble-shoot it. There may be modifications which would tend to complicate a circuit, but any combination of devices can be resolved into an equivalent switching and load function.

If we now substitute the lamp circuit with a relay and a momentary type pushbutton, holding the button depressed energizes the relay coil. This isn't very useful in automatic circuitry because releasing the button opens the circuit and de-energizes the coil. It does have a purpose in jog circuits or any circuit where the operator has complete control over the machine operation. Pushing the START button now energizes relay CR1 which causes the normally open contact CR1 to close. The current from line 1 now has two paths to follow; one through the pushbutton and the other through CR1 contact. Since there are two paths, releasing the button will allow the relay coil to remain energized. To de-energize the coil can be done by pressing and opening the STOP button.

Note the similarity between this circuit and the light bulb. Here CR1 is the load function, the same as the light, and the two pushbuttons and interlocking contact do the same electrical function as the switch, that is, close and maintain

a circuit to the load. All relay circuits can be analyzed this way.

This same circuit is used in a standard motor control arrangement by substituting a starter in place of the relay.

It will be noted that quite a bit more has been added to the circuit. For instance, we have shown a circuit breaker (CB1), control transformer, fuses (F1), motor thermal overloads (M1OL), overload relay contacts (M1OL), the motor load contacts (M1), and the auxiliary control or interlock contact of the starter (M1). We have given each device an identification, applied numbers to all connection terminating points and located the line position of the starter control contact (2). These are all necessary for an easier understanding of any diagram.

BASIC APPLICATION CIRCUITS

Now that some of the more widely used control devices have been discussed, we will work up a few basic application circuits.

CASE #1 - Using single solenoid spring-offset valves, it is desired to cause two slides to move forward and remain there. The slides can be returned by de-energizing the solenoids.

Two initiating methods have been shown as well as two solenoid control circuits. In circuit A, a relay and momentary type pushbutton are used. Also, solenoid A (line 2) is shown in parallel with the coil of 1CR while solenoid B (line 3) is controlled from a separate contact of 1CR. This is only to point out that both methods are correct; however, solenoid B with its separate contact is preferred. One big advantage for the separate contact control is in trouble-shooting. Circuit B, using a selector switch, also fulfills the requirements of the problem. The mechanical design and situation may dictate which circuit to use.

Circuit A is safer in that it requires operator attendance to bring the slides forward once the solenoids have been de-energized. Considering a power failure, if the slides were forward, loss of power would return the slides by de-energizing the solenoids. They would not come forward again until the "slides forward" button is pushed, since 1CR is also de-energized.

In Circuit B, with the selector in the "forward" position, a loss of power would de-energize the solenoids causing the slides to return, but a resumption of power would energize them immediately since the selector remained in its "forward" select position.

CASE #2 - It is desired to bring Slide A forward by pushbutton control. After a time delay, Slide B is to come forward. Both slides are to be returned by pushbutton. Pressing the "slides forward" button energizes the time delay relay which immediately closes its instantaneous contacts on line 2 forming a holding circuit around the pushbutton, and line 3, energizing solenoid A. When the time delay relay times out, timing contact 1TD on line 4 will close, energizing solenoid B. The time delay relay

and both solenoids will remain energized until the "slides return" button is pressed, de-energizing 1TD.

CASE #3 - After closing a gate and tripping a limit switch, pressing a start button will energize a solenoid causing a slide to go forward. After a time delay a second solenoid energizes causing another slide to go forward. When the second slide reaches its forward position it will trip a limit switch causing both slides to return, resetting the circuit. The slides can be returned at any time by pushbutton.

Limit switch LS1 must first be closed by closing the gate. The "slides forward" pushbutton can then energize 1TD which, in turn, closes the instantaneous contacts forming an interlock and energizing solenoid A. When 1TD times out, its timing contact closes (line 4) energizing solenoid B. Slide B starts its forward motion. At its forward position the slide trips LS2, causing it to open. This action de-energizes the coil of 1TD, opening its contacts, de-energizing the solenoids and resetting the circuit.

CASE #4 - After closing a gate and tripping a limit switch, it is desired to close a movable die plate by pressing the start button. During the closing stroke another solenoid is energized by a limit switch, resulting in a lower closing pressure. At the same time, a time delay relay is to be energized. If the dies continue to close before the time delay times out, the limit switch will release and open. If the time delay times out before the limit switch opens due to a slowing down of the die motion, then the closing solenoid will de-energize causing the dies to close.

Closing the gate trips LS1. Pressing the "close die" pushbutton energizes 1CR relay closing its contacts on lines 2, 3 and 4 resulting in a holding interlock circuit around the pushbutton, and solenoid A energizing, allowing the dies to close. As the dies close LS2 trips which energizes solenoid B and the time delay relay 1TD. If the dies continue closing until they meet or lock-up, then LS2 releases, opening the circuit and de-energizing solenoid B and the time delay 1TD. Since the time delay relay had not timed out, the timing contact on line 1 remained closed allowing relay 1CR and solenoid A to stay energized. The dies could then be opened by the "open die" pushbutton.

If during the closing stroke, the die motion were retarded by some obstacle between the die faces, then the time delay relay would time out before LS2 released. This would cause the timing contact of 1TD to open (line 1), de-energizing 1CR, solenoids A and B, the time delay relay and resetting the circuit. The dies would open and remain open until the "close die" button is pressed once again. The four preceding cases have attempted to show typical circuits based upon simple problems. The ability to read these circuits and thoroughly understand what mechanical, hydraulic or load action is taking place is adequate preparation for the more complicated types of machine wiring diagrams. In fact, these circuits are

repeated in many wiring diagrams.

One thing we have attempted to emphasize in these basic application circuits is the necessity for a good operational sequence of the machine action. Just looking at the wiring diagram in Case #4 without the operational sequence would not give the reader sufficient information concerning the action of the low pressure limit switch, solenoid and time delay. If the operation is not understood then attempting to shoot trouble would be more difficult.

Also brought to the reader's attention in these examples was the use of numbers interconnecting the device components, identification of devices, and the numbering of horizontal circuits for quick location and reference of components. These are all aids to help understand a diagram and trouble-shoot a machine

SIMPLIFIED IMM CIRCUIT

All of the preceding has been a preparation for reading wiring diagrams and trouble shooting a machine by the diagram. Let us now examine a simplified injection molding machine circuit.

This machine will be driven by a 20HP motor at 230 volts, 3 phase, 60 cycles. The control circuit will be 115 volts. There are to be three zones of heat controlled by pyrometers. There is one limit switch tripped by the safety gate when closed and another tripped when the dies open.

For safety reasons it is required to monitor the condition of the gate limit switch and prevent the dies from closing if the switch fails to revert back to its normal position. It is also required that the dies be fully open before a new cycle can be started.

1. Closing the safety gate will trip its limit switch energizing the "close die" solenoid.

2. As the dies close, another limit switch trips energizing a low pressure solenoid and a time delay relay.

    a. If the dies lock-up before the time delay relay times out, the low pressure solenoid and time delay de-energize.

    b. If the time delay times out before lock-up, the dies will open.

3. The dies close and lock tripping a limit switch causing the plunger to inject.

4. When the plunger injects, it remains forward for an adjusted amount of time.

5. At time out, the plunger forward solenoid de-energizes and the screw starts turning.

6. When the screw reaches its back position it trips a limit switch de-energizing the screw solenoid.

7. When the die close timer times out, the die close solenoid de-energizes and the die open solenoid energizes. The dies will open, tripping a limit switch at the full open position to de-energize the die open solenoid.

8. A new cycle cannot be started until the gate is opened and closed again.

The limit switch identification and trip action is noted as follows:

LS1 - Safety Gate	- Trips when the gate is closed.
LS2 - Die Full Open	- Trips when the dies are fully opened.
LS3 - Low Pressure	- Trips during the die closing stroke; releases just before lock-up.
LS4 - Lock-up	- Trips when the dies lock-up.
LS5 - Screw Stop	- Trips when the screw returns.

In order to operate the pumps, there must be a motor and starter circuit. This typical motor circuit shows a circuit breaker, control transformer, protective fuses, magnetic starter, overloads, start and stop pushbuttons and an interlock circuit. Since all control should be 110 volts, the heater contactors are controlled from the machine control circuit.

Lines 11-13 satisfy the initial requirement to monitor the gate limit switch and cause the dies to be fully open before a new close die cycle can be started.

Lines 14 and 22 satisfy item 1 of the sequence by closing the safety gate to energize the close die solenoid.

Lines 15 and 23 satisfy item 2a. Time delay contacts in line 11 and relay 1CR contacts in lines 14 and 26 will satisfy 2b.

Line 17 shows the lock-up limit switch which causes relay 4CR and its plunger in solenoid on line 24 to energize. At the same time, the screw motor solenoid is held de-energized by the normally closed contact on line 25. Timer T1 also energizes to fulfill the requirements of items 3 and 4.

When timer T1 times out, its normally closed timing contact opens on line 17, de-energizing relay 4CR and the plunger in solenoid on line 24. Since the screw is forward at this time, LS5 is in its normally closed position. The screw motor solenoid can energize causing the screw to turn and return to its back position as required in item 6.

Also, when timer T1 timed out, its normally open timing contact (line 20) closed, starting timer T2 (item 5).

Line 11 shows the normally closed timing contact of T2 which opens at time out to de-energize 1CR. This action causes the normally open 1CR contact on line 14 to open de-energizing 3CR, 4CR, T1 and T2 on lines 14 to 21. The die close solenoid on line 22 also de-energizes. Since 1CR and 2CR are now de-energized (the die open

limit switch is released with the dies forward), the die open solenoid on line 26 will now energize. The dies will open fully and trip LS2 to again energize 2CR which will now de-energize the die open solenoid to satisfy item 7.

Since the safety gate has not yet been opened, LS1 on line 11 is held tripped in the open position. 1CR is still de-energized. Even though LS1 on line 14 is held closed, the N.O. contact of 1CR prevents a recycle. This satisfies the condition of item 8.

In this example we did not describe a low pressure fault condition during the closing cycle. Its action would be such that when LS3 trips, 1TD would energize. Assuming 1TD timed out, due to a low pressure fault, before LS3 had a chance to release, its timing contact on line 11 would open to de-energize 1CR, 3CR and the die close solenoid. 1TD would reset and the die open solenoid would energize, causing the dies to return. The dies would not close again until the gate was opened and closed.

We have set up a problem, outlined a sequence of operation, shown a typical elementary wiring diagram which would conform to the required sequence, and read it through. As we read the diagram, it should have been noticed that an understanding of the sequence and knowledge of the machine action is extremely important.

Consider the intercommection diagram for this circuit. Everything shown on the motor, heater and control circuit drawings should be duplicated and represented here. The panel devices are shown exactly as they would appear on the panel assembly. The wiring table shows the wire connections exactly as the elementary diagram indicates. Pushbuttons and timers that are door mounted may be shown from the rear view to aid the electrician as he wires these devices. Remember, the interconnection diagram is merely an aid for wiring and tracing lines. The elementary diagram is the basic source of information.

TROUBLE SHOOTING

One of the most important uses for a wiring diagram is for locating faults or trouble-shooting improper operations. Fundamentally, trouble-shooting a machine requires no more knowledge than trouble-shooting an electric light and its associated switch. In order for the light to go on, the switch must be closed. Failure of the light bulb to light can be resolved into three basic reasons: (1) a burned-out bulb, (2) a faulty switch, and (3) a broken wire.

On a machine, the load can be a relay coil, a solenoid, timer, motor, heater or any other electrically operated device. The switch may be a combination of limit switches, relay contacts, timer contacts, pushbuttons, selector switches, or pressure switch contacts. The combined action, however, must be resolved into an equivalent circuit of switch and load.

The reason for trouble-shooting is to find the cause of a machine malfunction due to improper sequence of cycle or failure of a load to react. The reason for a load to react improperly is that it has been damaged either electrically or mechanically, or that it has not received a proper signal to cause it to react. In the light bulb analogy, it is reasonably clear that to light the bulb, the switch must be closed. That means there must be a continuity of circuit from one power line to one side of the bulb, through the bulb, and finally to the other power line. In a machine circuit, the same holds true. Regardless of the number of relay contacts, limit switch contacts, selector switches, or any other type of contact, all contacts must be closed in order for the current to energize its load.

Failure of any one contact to be closed, therefore, prevents the load from energizing. If all contacts are closed and the load still does not react, then the next possibilities are burned out coils of the load, broken wires, bad connections, or lack of power.

This basically is the understanding that must be employed in electrical trouble-shooting: First, locate the faulty load; secondly, find the cause; and third, correct the fault.

One of the best aids a trouble-shooter can devise, as a complement to the wiring diagram, is some form of a check list. It is quite conceivable that a detailed list could be made out for each wiring diagram, but more practical that one be made for each type of machine. An easy type of list to follow and understand is a check sheet broken down into three columns titled: TROUBLE, CAUSE and REMEDY. This type of list is quite adequate because it can be broken down to many possible causes that affect a particular trouble area and, in addition, the multiple remedies for correcting each cause. Everything listed on such a check sheet can be read from the wiring diagram. An example of the trouble shooting guide for injection molding machines is shown on the following pages.

INJECTION MOLDING MACHINE - ELECTRICAL TROUBLE-SHOOTING GUIDE

Note: It must be realized that loose or broken terminal connections are always a possibility for improper or erratic machine operation. Since this is general, the cause and remedy of such situations are not included in the trouble-shooting breakdown.

TROUBLE	CAUSE	REMEDY
A. Pump Circuit		
Motor will not start.	Power not connected.	Trip circuit breaker.
	Overload tripped.	Reset overload.
	Open circuit in stator or rotor.	Test motor for open circuit.
	Short circuit in stator.	Test motor for short.
	Wrong control connections.	Check wiring against diagram.
	Pushbuttons not making contact.	Test for continuity.
	Open starter coil.	Test coil.
Motor does not run when start button is released.	Faulty interlock circuit.	Check starter holding contact connections.
B. Die and Safety Circuit		
Dies do not close when gate is closed.	No control voltage.	Check circuit voltage with pump running.
	Die control relay not energized.	1. Test coil. 2. Check gate limit switch contacts for continuity. 3. Check open die limit switch. It should be tripped. 4. Check the normally closed contact of monitor relay for continuity. 5. Check normally closed contact of die close timer for continuity.

INJECTION MOLDING MACHINE - ELECTRICAL TROUBLE-SHOOTING GUIDE (Cont'd.)

TROUBLE	CAUSE	REMEDY
B. Die and Safety Circuit (Cont'd.)		
	Gate limit switch not tripped when gate is closed	1. Check cam and roller arm adjustment. 2. Check switches for continuity.
	Close die solenoid not energizing.	1. Monitor relay not energizing or making contact. 2. Die close limit switch not making contact.
C. Plunger Circuit		
Plunger does not inject during cycle.	Solenoid not energized.	1. Check plunger-in solenoid. 2. Check plunger relay. 3. Die lock-up limit switch not tripping. 4. Plunger forward timer contact should be closed. Check for continuity.
Screw does not return.	Screw motor solenoid not energized.	1. Check screw solenoid. 2. Check plunger relay. 3. Plunger forward timer should be timed out and its normally closed contact open. 4. Check normally closed contact of screw stop limit switch for continuity.
D. Low Pressure Circuit		
Low pressure inoperative.	Solenoid not energized.	1. Test solenoid. 2. Check low pressure limit switch.
Dies fail to open after low pressure operates.	Relay contacts not closing.	1. Check continuity of relay contacts.

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MOLDS AND OPERATING REQUIREMENTS

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INTRODUCTION

This discussion is weighted by our experience with molds over the last several years. We have found that one cannot intelligently discuss a mold, i.e., its operating requirements, design approach and performance, without taking a look at the system as a whole (material, machinery, mold and product). For instance, it makes little difference whether you have a well designed mold or a poorly designed mold - if the melt quality at the extruder nozzle is not what it should be, unacceptable parts will result.

Generally, it is possible to make acceptable parts with a poorly designed mold but it is more often than not impossible to optimize the cycle. It is self evident that a machine running on a cycle that is greater than optimum is a very costly operation. The unfortunate thing is that many molds are not running at the optimum cycle and the molder doesn't know it.

Therefore, this discussion will be centered around the approach we took to optimize the performance of existing molds and the use of this data to design new molds.

DESIGN OF RUNNERS & GATES

Because of the wide variety of products and methods of handling after molding it is almost impossible to discuss in detail all the design approaches available for runners and gates. It is essential to give the design careful consideration since the runner and gate is to the mold as the screw is to the extruder.

In order to achieve the best molding conditions, it is desirable to have a geometrically and thermally balanced runner system. The foregoing statement is to mold design as Newton's Laws are to dynamic analysis, i.e., easy to say but difficult to implement.

Figures 1A, 1B and 1C show a series of partial shots on a 24-cavity mold. Note that the center cavities are filled and the corner cavities have just started. A common problem with this type of mold is "flashing" the center cavities and "sinks" and cold flow in the corner cavities. In order to understand the circumstances a little better we decided to install some instrumentation on a $3\frac{1}{2}$" - 20/1 screw transfer type machine. A displacement and pressure transducer was used on the transfer plunger. The data was recorded on a conventional 12 channel oscillograph. The melt temperature was taken using a conventional needle point pyrometer. By taking a series of air and partial shots we readily determined what the pressure

drop was in various sections of the mold. A typical record is shown in Figures 2 and 3. By carefully studying the records and the partial shots, it was readily determined that the lower so-called holding pressure was useless with this mold. We judged, however, that it would be desirable to fill out approximately 90 - 95% of the mold under high pressures and plunger velocity and drop off to a slower speed and lower pressure for the last 5 - 10% of the volume.

The pressure drop throughout the mold was calculated and compared to the data. Although the theoretical pressure drop did not agree with the measured data as well as we hoped, it was considered accurate enough to use as the basis for a redesign. The design approach was essentially to "choke-off" the runners to increase pressure drop on those branches of the runner closest to the main sprue. Figures 4A, 4B, 4C and 4D show a series of partial shots that were taken after the runner was pressure balanced.

The phrase "pressure balance" is somewhat of a misnomer in that one must be assured that the melt viscosity, etc., are essentially constant. We found from other testing that the melt temperature varied as much as 50°F from the main sprue to the end nozzle and gate.

HEAT TRANSFER AND PROPER DESIGN REQUIREMENTS

It is often difficult, but seldom impossible, to predict the change in melt temperature from one end of the frame to the other. Since most molds are 3-dimensional transient type problems, it does take some experience in order to make the appropriate assumption and reduce both the analytical complexities and the corresponding engineering cost. The degree of emphasis one puts on mold temperature control does, to a large extent, determine whether or not a detailed heat transfer analysis is required. When molding heavy section parts, mold temperature control is mandatory otherwise the cycles become uneconomical on a conventional high pressure machine. Mold temperature control has a less dramatic effect on small, thin sections. Contrasting these two sets of circumstances, one might conclude that heat transfer analysis and good mold temperature control are not necessary on smaller parts; and generally, this is true. However, before one can establish such a general rule, you should be guided by the volume of parts produced or the length of the production run. On some items, the difference between a success and a failure in terms of both quality and dollars, is one or two seconds. The only realistic way to assure that the optimum cycle has been achieved is through sound heat transfer, flow analysis and good mold temperature control.

Mold temperature control is often interpreted to mean the use of a chiller. Although this is often the case, it is not necessarily the rule. If one considers an absolute minimum cycle, then I think it would be fairly accurate to say that a chiller would be required. We have found, however, that minimum cycle and optimum cycle are not necessarily the same. On one product we ran experiments to determine the minimum practical cycle (as manifold type mold). After several days of experimenting we achieved a twenty-five second cycle. We were, as a matter of fact, quite pleased with the results since the original cycle was some 70 seconds. After running at this cycle for several hours, a young woman opened a fire door because the plant was a little warm. Every single nozzle in the frame froze off and we were some 1/2 to 3/4 of an hour clearing the nozzles before we were back in production.

Although we generated a significant amount of detailed data which was of general value in the day-to-day operation, the most important information was more long range in nature, i.e.,

1. The general plant arrangement and facilities were not suitable to sustain a high level of production.

2. The molds were generally too sensitive to ambient conditions and required a redesign to thermally balance the frame.

3. The entire post-cooling equipment required redesign to sustain higher production rates.

In other cases where our manual gate time was in the same order of magnitude as our machine time, we found that normal variations in the human element were sufficient to cause wide variations in the number of usable products produced per shot. Therefore, in order to optimize the molding operation, we faced one of two alternatives:

1. Increase the total length of the cycle, i.e., make it less sensitive to the human element (short range).

2. Install automatic stripping equipment and remove the human element entirely (long range).

In summary, there are a number of elements which affect the optimization of a molding cycle. Those responsible for engineering the mold must recognize that the minimum cycle and the optimum cycle are not necessarily the same. The optimum cycle should be interpreted as best cycle possible under a given set of circumstances. For example, the production run and/or number of products molded, might not support an investment in an automatic sweep. That being the case, the optimum cycle must be set to compensate for the human element.

DEVELOP AND PROPER CONTROL OVER MOLD/MACHINE & PROCEDURE

The effect of the human element in molding has often gone unrecognized by some companies for years. It is a serious problem because it limits the ability of management to control the profitability of the company.

In many larger companies the "crystal ball" molder is being replaced by individuals with some technical training. Probably the most significant portion of the engineer training is in the application of the scientific method. To follow this procedure does not guarantee immediate success but one can be reasonably well assured that the data generated will be usable for long term progress.

By following this procedure on such mundane activities as machine maintenance, mold set-up, mold maintenance, and molding procedures, one may be very surprised to find not only how little the people on the floor actually know, but also how important and difficult it is to write instruction procedures so that the work gets done properly.

As an example, the engineering group was assigned the task of writing a set of operating instructions for the maintenance, handling and set-up of molds. We found as a result of preliminary investigation, that the cavities were being mistreated, stored in a damaged state, etc. The molding superintendent complained that he had no one to repair the cavities and actually didn't know how many cavities were damaged. It was decided that the entire responsibility for the tools would be delegated to the engineering group and not the manufacturing group.

We decided to categorize the nature of the damage and then try to find out how

it occurred (see sample data sheet, Appendix I). Through a combination of observing the cavity installation and removal procedure, the machine start-up and actually getting in there and doing the job ourselves, we learned enough about the operation to sit down and write the procedures.

As a bonus, we also found some major problem areas which could not be resolved via good handling and set-up procedures.

For instance, we found that in order to get the manifold mold running, the set-up man had to get into the mold each shot and pick off the frozen bud. In some cases, it was merely a flick of the wrist and in other cases he had to dig and pry. It generally took anywhere between $\frac{1}{4}$-$\frac{1}{2}$ hour to get the machine running again after a cavity change. We noted that the set-up men were not using the brass rods that were prescribed for this activity but were instead using a sharp pointed knife (58Rc). We found after trying it ourselves, that the brass rods were ineffective and the knives were almost a necessity. The knives, however, were harder than both the highly polished cavity and the manifold nozzle. The result was that each time the set-up man dug the bud out of the nozzle, he not only damaged the nozzle further but it got progressively more difficult to remove the frozen plastics bud. It eventually got to a point where his hand would slip and it resulted in a deep scratch in the cavity. I'm sure that the solution is obvious, i.e., harden the manifold nozzle and anneal the pointed knives. This step not only reduced the start-up time but considerably reduced the level of cavity damage.

In another case, we found that certain cavities were flashing badly and the manufacturing group felt that the dimensions were below tolerance. After inspecting the cavity it was found to be below tolerance but judged to be acceptable for production. This raised several questions, such as:

1. Were the tolerances realistic?

2. Could the mold maker actually meet the requirements?

3. How were the tolerances established?

4. What effect did the combination of tolerance for the machine, mold frame and cavity have on the flashing problem?

5. What level of tolerance are we talking about when we say force and cavity half must fit perfectly?

We found after extensive testing that we could get a near perfect cavity (dimensionally), set up in a mold frame so that the force and cavity half fit as nearly perfect as we could get (within 0.0005) by shimmering. We varied the molding pressure over a wide range (7000 psi to 16,000 psi) and had no problems with flashing. The cavities were set up in the normal manner and spray coated with "tool maker's prussian blue". After opening and closing the platen we found that the color transfer pattern duplicated the shape of the bow in the frame. This step, of course, was qualitative and we obtained quantitation data by trial and error (using shims). We then established what we termed "frame shims", i.e., those that would be used with that frame regardless of the cavity dimensions. Those cavities that were above the allowed tolerance were ground to size; those that were below tolerance we prescribed the appropriate size cavity shim until such time as that cavity could be repaired.

These tests, etc., were carried on over a period of months and after gathering all the information together a preliminary document was prepared which covered step

by step how management expected each function to be performed. Although this document was incomplete it was the first time management could say they knew what they wanted and why. It was also the first time the people in the molding department knew what was expected of them.

Developing proper molding procedures is straight forward enough if you are fully cognizant of the quality requirements. Because the establishment of good molding procedure (or machine operation) is governed by many things such as the product, quality, type frame, type machine and material. I will not go into any detail. A study to establish such a procedure is extremely important, however. We were able to increase our yield on one product line from approximately 200 pair/day/cavity to approximately 600 pair/day/cavity.

If, when these procedures have been established and written down in the form of a manual it becomes a very useful management tool. Such a manual is certainly no panacea and would not replace good supervision. If such a manual is used properly, however, it can be of great assistance when training new people, answering routine procedural questions, etc. An outline of our manual is attached for reference (Appendix II).

APPENDIX I

1. Inspection, Maintenance, Care in Handling and Installation Procedures for Cavities

1.1 New Cavity Inspection Procedure

- 1.1.1 Receiving (administrative) and Receiving Inspection
- 1.1.2 General Cavity Inspection Procedure
- 1.1.3 Cavity Parting-line Inspection Procedure
  - 1.1.3.1 General
  - 1.1.3.2 Two-piece Vinyl Heel Cavities
  - 1.1.3.3 Three-piece ABS Heel Cavities
  - 1.1.3.4 Heel-Sole Unit Cavities (low pressure)
  - 1.1.3.5 Heel-Sole Unit Cavities (high pressure)
- 1.1.4 Cavity Outside Dimension Inspection Procedure

1.2 Used Cavity Inspection and Maintenance Procedure

- 1.2.1 General Rules - Molding Departments and Tool Room
- 1.2.2 Administrative Procedure
- 1.2.3 Cleaning Procedure
- 1.2.4 Preliminary Inspection
- 1.2.5 Repair Procedure

1.3 Care in Handling

- 1.3.1 Introduction
- 1.3.2 Cavity Room
  - 1.3.2.1 Cavity Transfer and Shipment
- 1.3.3 Molding Department

1.4 Cavity Installation Procedures

- 1.4.1 General
- 1.4.2 Two-piece Vinyl Cavities
- 1.4.3 Three-piece ABS Cavities
- 1.4.4 Heel-Sole Unit Cavities (low pressure)
- 1.4.5 Heel - Sole Unit Cavities (high pressure)

2. Inspection, Maintenance, Care in Handling and Installation Procedure for Frames

3. Inspection and General Maintenance of Molding Machines

4. General Instructions for Operating Molding Machines to Achieve Optimum Quality and Maximum Production

5. General Operating and Maintenance Instructions for Auxiliary Equipment

6. Safety

APPENDIX II

INCOMING
CAVITY INSPECTION SHEET

DATE______________

Cavities received from______________

Cavities sent to______________

STYLE	SIZE	SCRATCH CAVITY	SCRATCH BREAST PLATE	NICKS LEADING EDGE BREAST CAVITY HALF	NICKS ON RIM	TOPLIFT END K O PIN DAMAGED	MARKS ON CUP	NICKS ON BREAST PLATE	REMARKS

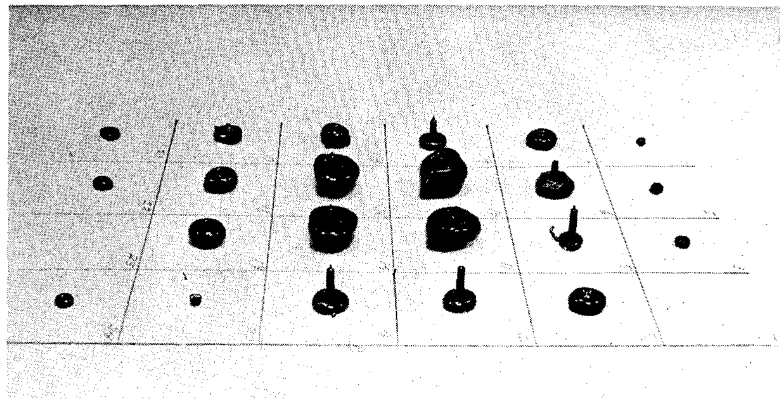

FIGURE 1A

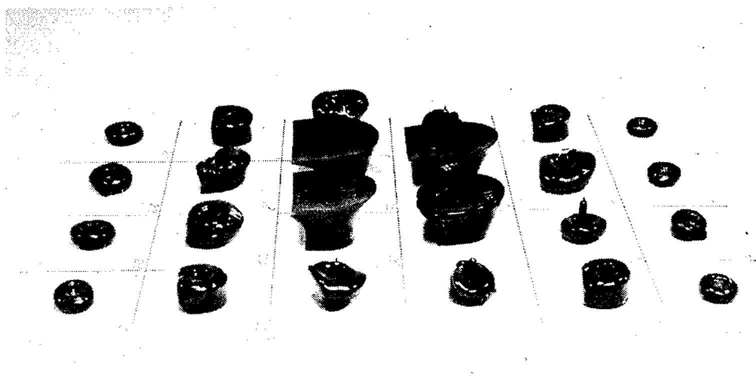

FIGURE 1B

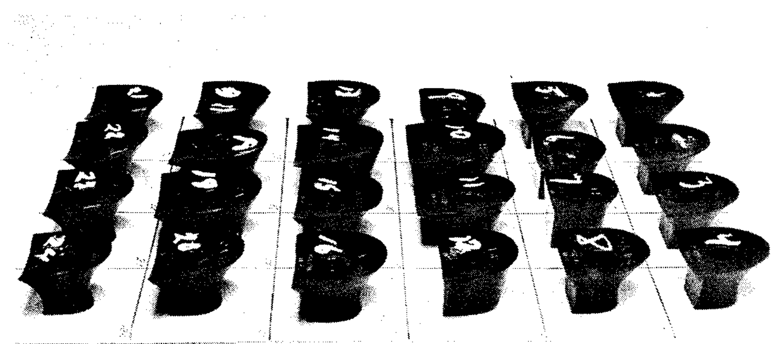

FIGURE 1C

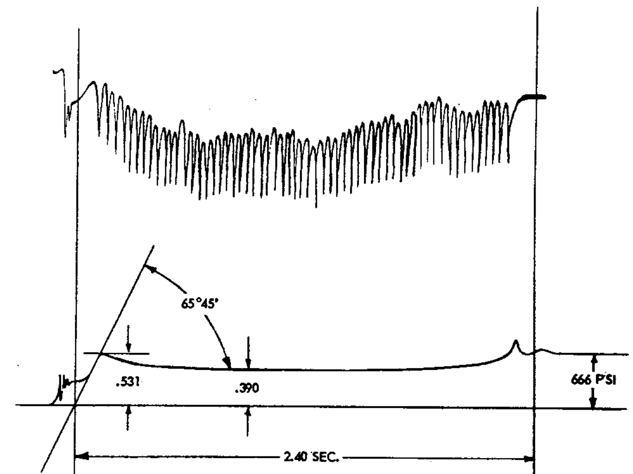

FIGURE 2

FIGURE 2

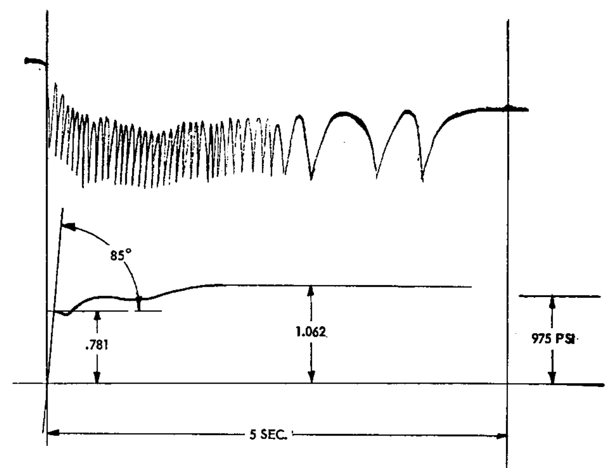

FIGURE 3

FIGURE 3

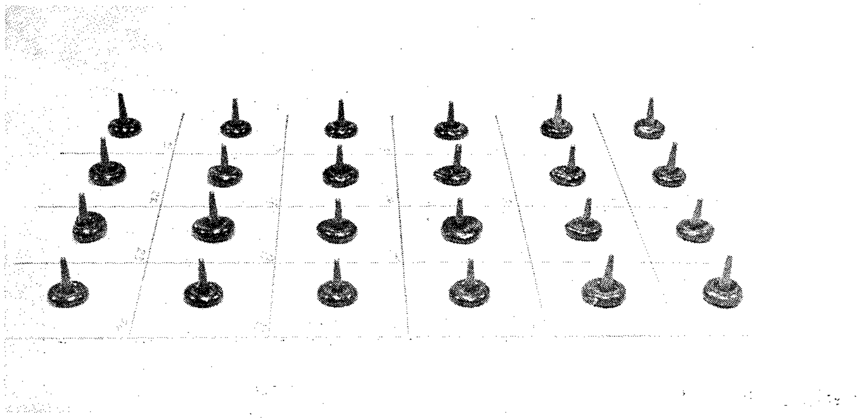

FIGURE 4A

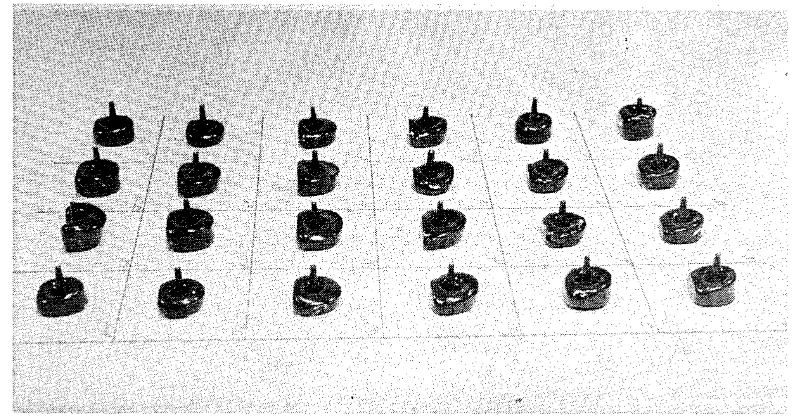

FIGURE 4B

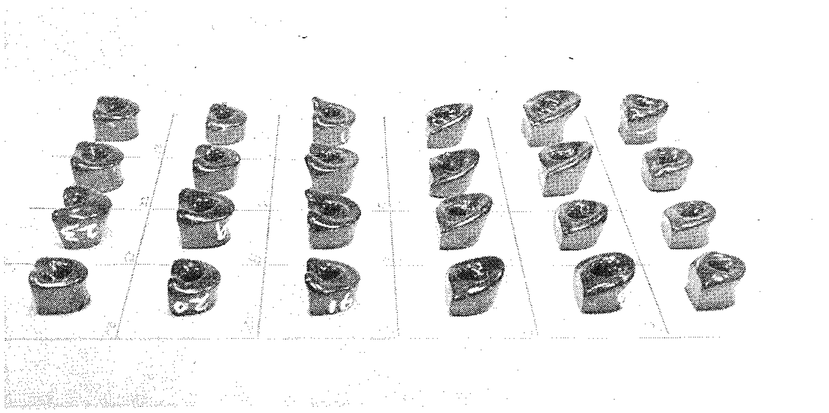

FIGURE 4C

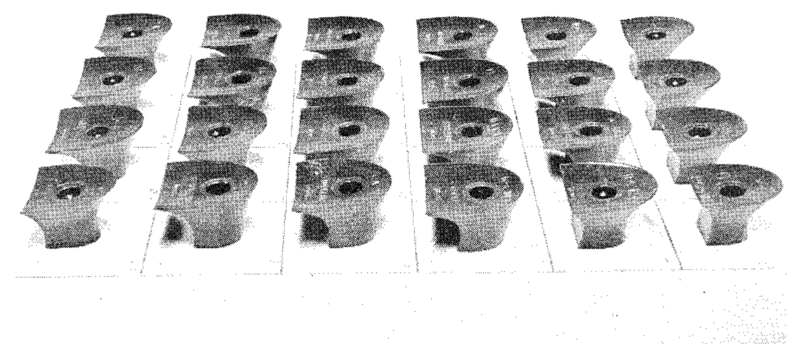

FIGURE 4D

INITIATION FEE MUST BE ATTACHED FOR PROCESSING.

SOCIETY OF PLASTICS ENGINEERS, INC.

65 Prospect Street, Stamford, Conn. 06902
348-7528 AREA CODE 203

MEMBERSHIP APPLICATION

PLEASE PRINT OR TYPE

Executive Office Use Only
I.D. No. ______
Ack. ______
Elected ______

I hereby make application for { ☐ admission into / ☐ reclassification within / ☐ reinstatement in } the Society of Plastics Engineers, Inc. in the grade of membership indicated below for which I believe I am qualified. (See instructions or reverse side.)

Grade	Initiation Fees	Annual Dues	Foreign Dues
☐ Senior Member	$10.00	$20.00	$17.50
☐ Member	10.00	20.00	17.50
☐ Affiliate Member	10.00	20.00	17.50
☐ Student Member	None	5.00	5.00

I wish to affiliate with the ______ section.
(Geographical location. See listing on reverse side.)

Applicants Full Name ______
(First) (M.I.) (Last) (Citizen of) (Birthdate)

Please fill in both addresses and **CHECK THE ONE TO WHICH YOUR MAIL SHOULD BE ADDRESSED.**

☐ **BUSINESS:** Company Name and Division: ______

Position ______

Address ______ City ______ State ______ Zip Code ______

☐ **HOME:** Address ______ City ______ State ______ Zip Code ______

REFERENCES The By-Laws require the names of three references who are familiar with your work. One of them should be a member of the Society. Assistance in providing member-references, when needed, will be given on request.

1. ______ Address ______
2. ______ Address ______
3. ______ Address ______

STATEMENT OF COLLEGE WORK

Years Attended From	Years Attended To	Institution	Major and Minor	Degree	Experience Credits See reverse side
				Total Education Experience Credits	

RECORD OF QUALIFYING EXPERIENCE IN PLASTICS

Dates From Mo.	Dates From Yr.	Dates To Mo.	Dates To Yr.	Give your title, name and location of employer, and name of immediate superior for each position. List in chronological order. Describe duties fully and state briefly any important engineering work you have done in in each position. If space is not sufficient, use a separate sheet.	Time in years and months
				Total qualifying years of experience.	
				Total education and qualifying experience credits.	

I certify that the statements made in this application are correct. I agree, if elected, to be governed by the Constitution and By-Laws of the Society, and to promote the objective of the Society.

NATIONAL CREDENTIALS COMMITTEE USE ONLY

Approved (Signature) ______ Date ______

Approved (Signature) ______ Date ______

______ Date of Application

______ Signature in ink.

COMPLETING THE APPLICATION

Grade of Membership . . .

Membership grades are based on experience credits which are earned as follows:

1. **Experience credits earned for education.**

   Doctorate in science or engineering subject: **6 credits**

   Masters in science or engineering subject: **5 credits**

   Bachelors in science or engineering subject: **4 credits**

   Other degree in non-science or non-engineering subject: **2 credits**

   Maximum credits allowable for education shall be six (6).

   When filling in the "Statement of College Work" on the reverse side of this application, please place the corresponding number of credits earned in the right-hand column.

2. **Experience credits** for qualifying experience in plastics or plastics engineering are earned at the rate of one (1) per year, e.g. 5½ years of qualifying experience = 5½ credits. *Please detail carefully the engineering skill required for* ***each position*** *to help the Credentials Committee judge experience as "qualifying."*

   When filling in the "Record of Qualifying Experience in Plastics" on the reverse side, please place the amount of time spent in each position (in years and months) in the right-hand column.

When you have determined the number of credits which you believe you have earned consult the following membership grade requirements. Indicate on the reverse side the grade of membership for which you believe you are qualified.

GRADE	REQUIREMENTS
Senior Member	Minimum of twelve (12) experience credits and maintained continuous membership in the Society for a minimum of two (2) years.
Member	Minimum of six (6) experience credits
Affiliate Member	Less than six (6) experience credits
Student Member	Regularly enrolled student (full- or part-time) in a course of study in plastics and between the ages of 16 years and 26 years, inclusive.

THIS PORTION MUST BE COMPLETED FOR PROCESSING OF YOUR APPLICATION.

Please check off the principal activity of your company under either Manufacturing or Non-Manufacturing.

MANUFACTURING

1. ☐ Electrical & Electronic Machinery, Equipment & Appliances
2. ☐ Motor Vehicles and Equipment
3. ☐ Transportation Equipment (except Motor Vehicles)
4. ☐ Professional, Scientific and Controlling Instruments, Photographic & Optical Goods, Clocks
5. ☐ Iron, Steel & Nonferrous Metals & Machinery (except Plastic & Electrical Machinery)
6. ☐ Fabricated Metal Products and Housewares
7. ☐ Finished Apparel Products
8. ☐ Food and Tobacco Products
9. ☐ Toilet Preparations, Drugs and Insecticides
10. ☐ Paints, Varnishes and Industrial Chemicals (except Plastic Raw Materials)
11. ☐ Petroleum, Coal, Rubber, Stone and Glass Products
12. ☐ Musical Instruments, Toys, Sporting Goods, Athletic Goods, Ordnance & Smokers' Supplies
13. ☐ Jewelry and Fashion Accessories
14. ☐ Furniture and Finished Wood Products
15. ☐ Leather and Leather Products
16. ☐ MANUFACTURING, other than above. Please specify ____
17. ☐ Plastics Custom Molders, Extruders, Laminators, and Fabricators
18. ☐ Plastic Materials
19. ☐ Producers and Processors of Textiles, Lumber, Paper, Oils, Dyes, Chemicals, etc. used in Manufacture of Plastics
20. ☐ Plastic Machinery

NON-MANUFACTURING

21. ☐ Government: Federal, State, Municipal and Foreign; Officers of the Armed Forces
22. ☐ Advertising Agencies, Sales Consultants and Sales Engineers
23. ☐ Libraries, Schools, Colleges and Trade Associations
24. ☐ Consultants and Research Organizations, Architects, Engineers, Designers, Chemists
25. ☐ Transportation Operating Companies
26. ☐ Retail Stores
27. ☐ Exporters, Importers, Distributors, Jobbers, Wholesalers and Manufacturers' Agents
28. ☐ Doctors, Lawyers and other Professionals
29. ☐ NON-MANUFACTURING, other than above. Please specify
30. ☐ Packaging & Containers
31. ☐ Aerospace
32. ☐ Construction Materials

MEMBERSHIP APPLICATION

SOCIETY OF PLASTICS ENGINEERS, INC.
65 Prospect Street, Stamford, Conn. 06902
348-7528 AREA CODE 203

SPE SECTIONS

AKRON	NORTHERN INDIANA
ARIZONA	NORTHWEST PENNSYLVANIA
BALTIMORE-WASHINGTON	OMAHA
BARTLESVILLE-TULSA	ONTARIO
BINGHAMTON	PACIFIC NORTHWEST
BUFFALO	PALISADES
CENTRAL INDIANA	PHILADELPHIA
CENTRAL NEW YORK	PIONEER VALLEY
CENTRAL OHIO	PITTSBURGH
CHICAGO	QUEBEC
CLEVELAND	ROCHESTER
CONNECTICUT	ROCK VALLEY
DELAWARE VALLEY	ROCKY MOUNTAIN
DETROIT	ST. LOUIS
EAST CENTRAL ILLINOIS	SOUTH TEXAS
EASTERN NEW ENGLAND	SOUTHEASTERN OHIO
FLORIDA	SOUTHERN
GOLDEN GATE	SOUTHERN CALIFORNIA
HUDSON-MOHAWK	SOUTHEASTERN NEW ENGLAND
JAPAN	SOUTHWEST VIRGINIA
KANSAS CITY	TENNESSEE VALLEY
KENTUCKIANA	TOLEDO
MIAMI VALLEY	TRI STATE
MID-MICHIGAN	UPPER MIDWEST
MILWAUKEE	VIRGINIA-CAROLINA
MONTERREY	WESTERN MICHIGAN
NEW YORK	WESTERN NEW ENGLAND
NEWARK	NON-SECTION
NORTH TEXAS	